FINAL REPORT

AN EVALUATION OF THE EFFECTIVENESS
of
AUTOMOBILE ENGINE ADJUSTMENTS TO
REDUCE EXHAUST EMISSIONS
and
AN EVALUATION OF THE TRAINING REQUIRED
TO DEVELOP PERSONNEL COMPETENT TO
MAKE THE ADJUSTMENTS

VOLUME II
TECHNICAL
REPORT

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FOREWORD

This final report consists of two volumes. The following are the titles given for each volume:

Volume I.	EXECUTIVE SUMMARY
Volume II.	TECHNICAL REPORT

The first volume summarizes the objectives, approach and results of the program. The second volume presents (1) a description of the program operations, (2) a discussion of pre-test preparations, (3) an analysis of the test results, and (3) the conclusions.

The emission tests presented herein were performed by the California Air Resources Board at the Montebello, California, test facility.

ABSTRACT

A study was conducted to explore two approaches for the control of exhaust emissions from used vehicles. The first approach involved the upgrading of Class A stations with exhaust analyzers and the training of Class A mechanics to perform low-emission tune-ups. Ten Class A mechanics, representative of Class A mechanics as a whole, attended a 40 hour training course. They learned how exhaust emissions relate to the condition of the engine. With this knowledge, they were "programmed" to:

1. Quickly diagnose engine defects that cause excessive emissions.
2. Repair these defects.
3. Maintain certain engine components to prevent malfunctions known to cause emission increases.
4. Perform low-emission adjustments.

The above steps reduced engines to their practical minimum pollution capability (MPC) and are referred to as an MPC tune-up. MPC tune-ups were completed on 300 vehicles representative of the 1957-1970 California vehicle population. Hydrocarbon (HC) and carbon monoxide (CO) emissions were reduced by 36.7% and 35.2% respectively. Exhaust oxides of nitrogen (NO_x) increased 5.6%. The average cost was $27.40. Fuel consumption was reduced by 5.0%. Interviews with the vehicle owners revealed that 54% of the vehicles performed better, 15% worse, and 31% with no change.

After an average mileage of 5283 miles and six months of service, the vehicles were retested. Degradation in emission control was small. HC and CO reductions were still 29.5% and 30% respectively. NO_x increase was 3.7%.

The second approach involving the vacuum spark advance disconnection (VSAD) on engines for NO_x control was studied to determine the vehicle owner's acceptance and possible side effects. The scope of the study was limited to driveability changes and side effects noticed by the vehicle owners during the first month of service. VSAD was provided on 100 vehicles previously given MPC tune-ups and 100 like vehicles with no other work performed on the engine. Fifty (50) vehicles representative of the 100 vehicle groups were equipped with "dummy" VSAD kits, therefore, establishing and compensating for owner bias in the data analysis.

The results showed that vehicle owners could not distinguish between the "real" and "dummy" VSAD kits when no other work was done to their engines. VSAD combined with the lean tuning in the MPC tune-up produced a change in driveability unacceptable to one out of five vehicle owners. An investigation of coolant overheating complaints showed that VSAD had a slight effect. Faulty cooling systems were the major cause of engine overheating.

CONTENTS

CONTENTS (cont.)

ILLUSTRATIONS

CONTENTS (cont.)

TABLES

CONTENTS (cont.)

CONTENTS (cont.)

I. INTRODUCTION

The purpose of this program was to determine the effectiveness, cost and vehicle owner's acceptance of two approaches for the control of used vehicle exhaust emissions. The first approach consists of upgrading the California Class A stations with the equipment and trained mechanics needed to periodically diagnose, repair, maintain and adjust engines in order to reduce each engine to its practical minimum pollution capability (MPC). This process is hereafter referred to as the MPC tune-up. It controls hydrocarbons (HC) and carbon monoxide (CO) in exhaust gases.

The second approach involves the disconnection of the engine's vacuum spark advance for the control of oxides of nitrogen (NO_x). The vacuum spark advance disconnection (hereafter referred to as VSAD) was accomplished by inserting a thermally actuated valve in the vacuum line leading to the distributor. This valve reinstates the spark advance if the engine coolant temperature exceeded 205°F.

These approaches were identified in a June 1971 report[1] by the late Technical Advisory Committee to the California Air Resources Board (ARB). This report entitled Emission Control of Used Cars; Available Options: Their Effectiveness, Cost and Feasibility concluded that: "Some form of annual inspection and maintenance will be necessary to obtain full benefit from other emission controls on either new or used cars. The best such system appears to be an annual inspection and maintenance to bring every car to its minimum pollution capability." The report also concluded that VSAD is the most cost effective of all options studied and can be done quickly.

As a result of these conclusions, this research program was conducted to examine these two promising control options under conditions which--insofar as possible--simulated the "real-world" situation.

The objectives of the program were to:

- Develop a cost-effective procedure for performing MPC tune-ups.
- Develop a mechanic training program and train ten Class A mechanics (representative of Class A mechanics as a whole) to perform MPC tune-ups.
- Determine the effectiveness, cost, savings in fuel consumption and owner acceptance of MPC tune-ups.
- Determine the degradation in emission reductions obtained with MPC tune-ups.
- Evaluate vehicle owner acceptance of VSAD on vehicles with MPC tune-ups and also on vehicles with no other work performed.

- Investigate any vehicle side effects which may occur within a month from the time of VSAD kit installations.

The program involved the solicitation and testing of four groups of vehicles representative of the 1957 through 1970 California vehicle population. The first group of 200 vehicles received MPC tune-ups. This group is referred to as "A" vehicles. The second group of 100 vehicles received the MPC tune-ups and two weeks later received VSAD kits. This group is referred to as "B" vehicles. The third group of 100 vehicles received VSAD kits only with no other work performed on the engine. This group is referred to as "C" vehicles. The fourth group of 50 vehicles received "dummy" VSAD kits which only appeared to provide VSAD. This group is referred to as "D" vehicles.

The Technical Discussion Section of this report is divided into two main parts. The first part covers the work performed on the MPC tune-up approach and the second part covers the VSAD approach. Each part describes the program operations, tasks performed in preparation for the vehicle tests, the test results, and the conclusions.

Test data for vehicles receiving MPC tune-ups is contained in Appendix A. The data includes:

- Tabulations of exhaust emissions, fuel consumption, and cost data for the vehicles classified by controlled (post-1965), uncontrolled (pre-1966), "A", and "B" groups of vehicles.

- Tabulations of idle and 2500 RPM (no-load) exhaust emission changes during the six month program.

- Tabulations of driveability and owner acceptance data for MPC tune-ups.

Test data for vehicles receiving VSAD kits is contained in Appendix B. This data includes tabulations of driveability and owners' acceptance data for "B", "C", and "D" vehicles.

Program operation and data forms are presented in Appendix C. Miscellaneous graphs, figures and program information are given in Appendix D.

II. SUMMARY

Two approaches to the control of exhaust emissions from used vehicles were studied. The first approach called the "MPC Tune-Up Approach" consists of diagnosing, repairing, and maintaining all engines to their practical minimum pollution capability (MPC). The second approach involves vacuum spark advance disconnection (VSAD) on engines for NO_x control. Studies of these two approaches are summarized under separate headings below.

A. MPC TUNE-UP APPROACH

Ten (10) Class A stations within a ten mile distance from the Air Resources Board (ARB) emission test facility at Montebello, California, were selected. These stations were representative of Class A stations as a whole. They included four new car dealers, four gasoline service stations, and two independent garages. A representative sample of ten (10) licensed mechanics was selected from these stations. The ages of the mechanics ranged from 20 to 50 years. The average age was 32 years. The experience of the Class A mechanics varied from three months to ten years. The average was four years. Each mechanic completed a 40 hour (one week) training course on the MPC tune-up procedure. A special feature of the course was that the mechanics were taught to relate engine operating conditions and defects with exhaust emissions. With this knowledge, they were "programmed" to:

1. Perform rapid diagnoses.

2. Make judgments of when to repair.

3. Perform cost-effective repairs.

4. Perform preventative maintenance on engine parts that may cause emissions to degrade within a year.

5. Perform low emission adjustments.

Each Class A station was equipped with additional instruments not presently required by the State. The price of these instruments range from $1500 to $2500.

Three hundred (300) vehicles representative of the 1957 thru 1970 California passenger vehicle population were:

1. Tested by the ARB,

2. Given MPC tune-ups at the ten upgraded Class A stations,

3. Retested by the ARB immediately after the MPC tune-up, and

4. Retested by the ARB after six months of service.

The driveability of the vehicles before and after MPC tune-ups was assessed by the vehicle owner and by technicians of Clean Air Research Company (CARCO).

Exhaust emission reductions attained initially and after six months are shown in Table 1. below:

TABLE 1

EMISSION TEST RESULTS - 7-MODE TEST CYCLE

EXHAUST EMISSIONS	INITIAL REDUCTION - %	REDUCTION AFTER 6 MOS. - %
Hydrocarbons (HC)	36.7	29.5
Carbon Monoxide (CO)	35.2	30.0
Oxides of Nitrogen (NO_x)	$\langle 5.6 \rangle$	$\langle 3.7 \rangle$

These results show that:

1. Substantial reductions in HC and CO can be attained by the MPC tune-up approach at a small increase in NO_x.

2. More importantly--the degradation of this emission control after six months was small.

The average miles traveled with the test vehicles during the six month period was 5283 miles. This is approximately 30% higher than the average for vehicles of this age group.

The average cost of the MPC tune-ups was $27.40. The average fuel consumption measured during the ARB 7-mode tests decreased by 5.0% immediately after the MPC tune-up. At the end of six months, the fuel consumption was still 3.7% less. This savings in fuel reduces the tune-up costs by about $10 per year for the average vehicle owner.

Driveability tests performed by CARCO technicians showed that the test fleet had 830 demerits before the MPC tune-ups and 470 after. These tests showed that 55% of the vehicles drove better, 29% drove worse, and 16% indicated no change. Two weeks after the MPC tune-up, interviews with the vehicle owners determined that 54% of the vehicles performed better, 15% worse, and 31% with no change. In interviews after six months, 74.5% of the vehicle owners stated that the change in their engine's performance was acceptable; 15.7% stated that the performance change was unacceptable; and 9.8% stated that the performance change would be acceptable if the MPC tune-ups were made mandatory by the State for air pollution control.

B. VSAD APPROACH

The ten Class A mechanics trained to perform MPC tune-ups were also trained to install VSAD kits. These kits were placed on a representative sample of 100 vehicles from the 300 vehicles previously given MPC tune-ups. Kits were also installed on another 100 vehicle sample like the 100 vehicle sample given MPC tune-ups.

In order to establish the effect of the vehicle owner's bias on his evaluation of driveability and other side effects, dummy kits were placed on 50 vehicles representative of the two 100 vehicle samples with operative VSAD kits. The driveability of the vehicles before and after the kit installations was assessed by the vehicle owners and by the trained technicians. The kits remained on the vehicles for one month. The owners' comments were obtained by questionnaires and an interview after one month.

The driveability results are given in Table 2.

TABLE 2

DRIVEABILITY EVALUATIONS

OBSERVER	BETTER - %			WORSE - %			NO CHANGE - %		
	MPC + VSAD	VSAD	DUMMY	MPC + VSAD	VSAD	DUMMY	MPC + VSAD	VSAD	DUMMY
Owner	22	35	32	41	35	48	37	30	20
CARCO Technicians	32	40	34	29	26	18	39	34	48

The above results indicate that the vehicle owners could not distinguish between the dummy kits and the VSAD kits installed with no other work done to the engines. The vehicle owners' driveability evaluations did show that the addition of VSAD on vehicles with MPC tune-ups produced more adverse changes in driveability than did VSAD on vehicles on which no other work was performed. These observations are substantiated by the vehicle owner's comments on acceptance and performance given in Table 3.

The numbers in the two right hand columns (VSAD ONLY and DUMMY) denoting the percentage of owners commenting on each item are remarkably close. This substantiates that vehicle owners could not tell the difference between the real VSAD kits and the dummy kits when no other work was performed on the engines. However, differences between

TABLE 3

OWNERS' COMMENTS

COMMENTS	% OF OWNERS COMMENTING		
	MPC + VSAD	VSAD ONLY	DUMMY
Not Acceptable	21	7	8
Acceptable	77	84	88
Acceptable if Mandatory	8	9	4
Overheating	11	4	6
Uses More Gasoline	28	18	16
Poorer Performance	23	6	6
Better Performance	11	11	14

the first two columns show that a larger number of owners reported a loss of performance when VSAD was combined with the MPC tune-up. Three times as many owners of vehicles with MPC tune-ups stated that the change (VSAD) was not acceptable. The major cause of this dissatisfaction is believed to be the combined loss of performance from the lean carburetor tuning provided by the MPC tune-up and the retarded spark timing from VSAD.

During the one month evaluation of VSAD kits in Los Angeles service, a severe heat wave was encountered. Several vehicle owners complained of engine overheating. Since overheating was one of the most likely side effects of VSAD, 13 vehicles were recalled for further studies. Seven vehicles were dynamometer tested at 80°F, 90°F, and 100°F. The results of this investigation showed that:

1. Only one of the 13 vehicles boiled over because of VSAD;
2. Seven of the vehicles boiled over because of leaking cooling systems;
3. Three of the vehicles would not boil over under the most severe test conditions;
4. One vehicle was equipped with a dummy kit; and
5. One vehicle was a false alarm.

This shows that a defective cooling system is a far greater cause of engine overheating than VSAD.

III. TECHNICAL DISCUSSION

A. INTRODUCTION

This section of the report is divided into two main parts. The first part discusses the training and test operations performed to determine the emission reductions and customer acceptance of tuning every vehicle to its minimum pollution capability (MPC). This part explains how Class A stations were upgraded with equipment to perform MPC tune-ups and how Class A mechanics were trained. It presents test results and evaluates the effectiveness of the training course and the MPC tune-up procedure employed.

The second part of this section discusses the program operations performed to evaluate owner acceptance and possible side effects of a VSAD type NOX control. The results of driveability tests are also discussed.

B. THE MPC TUNE-UP APPROACH TO EXHAUST EMISSION CONTROL

1. Program Operations

The MPC tune-up approach was evaluated by:

a. Developing a tune-up procedure to reduce engines to their practical MPC;

b. Selecting and upgrading ten (10) Class A stations with the equipment needed to complete the procedure;

c. Training ten (10) Class A mechanics to perform MPC tune-ups according to the procedure;

d. Selecting and soliciting 300 vehicles representative of the California population of 1957 through 1970 vehicles and testing their emissions and driveability as received from the owners;

e. Completing MPC tune-ups on each vehicle at the ten Class A stations;

f. Retesting the vehicles for emissions and driveability immediately after the MPC tune-ups;

g. Placing the vehicles in owner service for six months;

h. Retesting the vehicles for emissions and driveability after six months; and

i. Performing complete diagnoses of the engines to establish their state of tune and repair after the six month testing.

The actual program sequence that was completed on each vehicle involved many more steps than those listed above. These individual steps are shown in Table C-1 in Appendix C. As shown in this table, the vehicle owner was given a questionnaire to establish his opinion on how the vehicle drives before the MPC tune-up, immediately after the MPC tune-up, and after six months. This questionnaire is shown in Table C-2 in Appendix C. CARCO technicians also performed driveability tests at the same time as the owner. CARCO driveability tests were conducted in accordance with the form shown in Table C-3 of Appendix C.

The owners were also interviewed in two weeks and in six months after the MPC tune-ups to obtain answers to questions regarding the performance of their vehicles and to obtain unsolicited comments on possible side effects. These interviews were made according to forms shown in Tables C-4 and C-5 in Appendix C.

Emissions tests were performed at the ARB mobile test station at the Department of Motor Vehicles in Montebello, California. Hot 7-mode tests were performed. A total of four 7-mode cycles were performed in each test. Emissions were measured during the third and fourth cycles. The fuel consumed during the third and fourth cycles was also measured according to instructions given by the form in Table C-6 in Appendix C.

The last step of the sequence of events for each vehicle was the performance of a complete diagnosis of the engine. Form 9 shown in Table C-7 in Appendix C was used to document the diagnostic data.

2. Development of the MPC Tune-up Procedure

The MPC tune-up procedure was developed to reduce every vehicle to its practical MPC and in so far as possible, maintain these low emission levels for one year. The MPC tune-up is oriented toward emission reductions rather than improved performance; however, the repair of engine defects affecting emissions will usually result in better performance. The procedure consists of the following parts:

a. A thorough diagnosis using instruments to measure HC and CO exhaust emissions and other more common tune-up instruments to detect engine defects or deteriorated parts that are increasing tail pipe emissions or would likely cause increased emissions within a year or 10,000 miles.

b. The cost-effective repair of defects detected.

c. Preventative maintenance comprising of cleaning, repairing, or replacing parts that would likely cause increased emissions within a year or 10,000 miles.

The procedure was developed to reduce the following two major causes of excessive exhaust emissions from used vehicles:

a. Misfires of the air-fuel mixture due to faulty ignition systems.

b. Too rich or too lean air-fuel mixtures due to faulty carburetion.

These two causes of excessive emissions are briefly discussed under a separate heading as a background prior to a later discussion of the MPC tune-up procedure.

Other causes of excessive emissions, such as defective exhaust valves and worn-out piston rings, are detected in the diagnostic part of the MPC tune-up procedure but are not repaired. The MPC tune-up is limited to repair work that can be performed without removing the intake manifold, cylinder heads, oil pan or timing chain cover.

a. Ignition Misfires

There are two types of ignition misfires. The first type is the complete misfire of the air-fuel mixture in the cylinder on every power stroke regardless of the load or speed of the engine. This type is usually caused by broken wires and spark plugs that are badly fouled with deposits. The second type of ignition misfire occurs when the engine is operating under heavy loads and/or speeds. Under these conditions, the voltage requirements to fire plugs are the highest and incipient misfires are most likely to occur.

Complete misfires cause the greatest increase in emissions and are the easiest to detect. They are easily detected with an electronic oscilloscope and/or an HC instrument while the engine is running at idle or faster speeds without load. Incipient misfires are more difficult to detect without a chassis dynamometer because they usually occur under load. They can be detected by accelerating the engine and using the inertia of the rotating parts to load the engine. This procedure lacks precision because the load is applied for only a few seconds and the speed rapidly changes.

The CARCO MPC tune-up procedure, therefore, includes the use of a secondary ignition tester to simulate the conditions of a heavy load and high speed. This tester lowers the amptitude of the voltage available to fire spark plugs and shortens the time it is available. If the engine stalls out because the required voltage exceeds that available, then there is a marginal problem in the secondary ignition system which is likely to show up as an incipient misfire under load or will develop into a complete misfire in a few thousand miles.

Over 95% of the time, a problem detected with the secondary ignition tester will be spark plugs that should be replaced. Therefore, the tester is primarily used to determine if spark plugs should be replaced. The determination of whether spark plugs should be replaced is normally a difficult and time consuming job. The remaining life of the plug depends upon the gap between the electrodes and the type and amount of deposits formed on the plug. The use of the secondary tester to determine if the spark plugs should be replaced removes the subjective judgment of mechanics and reduces the cost of labor. This test is also referred to as the Fulton test.

A fouled spark plug is the largest cause of ignition misfires. The second largest cause is defective ignition wires. Wires become defective because they develop an open circuit or become grounded. Ignition wires commonly used with a graphite core instead of a copper wire conductor are particularly susceptible to open circuits. The graphite core breaks when the wire is bent or when the wire becomes brittle with age. These graphite core wires also develop an open circuit when they are pulled away from spark plug terminals at a time when the terminals are removed from spark plugs. Defective ignition wires are easily detected by an electronic oscilloscope and/or an HC instrument.

If the spark plugs and ignition wires are acceptable and the engine still fails the secondary ignition tester, other possible ignition system defects are investigated such as:

(1) Defective ignition points or capacitor

(2) A defective ignition coil

(3) A defective distributor rotor or cap

(4) Improper timing

b. Faulty Carburetion

Faulty carburetion causes emissions to increase when:

(1) The air -fuel ratio becomes so lean on one or more cylinders that the cylinder or cylinders misfire.

(2) The air-fuel ratio becomes so rich that combustion of the gasoline is incomplete.

Lean misfires are easily detected with an exhaust analyzer that measures both CO and HC. When the CO is low at idle, for example, and the HC either remains high or fluctuates between high and low, this indicates that lean misfire is present. This can be verified by richening the idle mixture and observing the HC meter. If the CO increases and the HC decreases, the carburetor was adjusted too lean.

There are other causes of lean misfires, such as leaks in vacuum hoses and intake manifold gaskets. Under these conditions, the air leak is likely to affect only one cylinder and the exhaust CO reading could be normal when the HC reading is too high. These leaks can usually be verified by increasing the engine speed from idle to 2500 RPM and observing the HC meter. If the HC decreases to normal, an air leak probably exists. Lean misfires can give the same symptoms as sticking or burned exhaust valves. However, they can be often separated by enrichening the carburetor at idle and observing the HC emissions. A more positive separation is a compression test on the cylinder that fails to slow the engine down when its spark plug is shorted out.

Excessive emissions from over-rich carburetion can be caused by many defects. A small degree of over-rich carburetion results in a proportional increase in CO. A large degree of over-rich carburetion also results in increased HC. Common causes of excessive enrichment are:

(1) Maladjusted carburetor idle screws

(2) Plugged PCV valves

(3) Plugged air cleaners

(4) Carburetor chokes that will not open completely

(5) Plugged air bleeds in the carburetor

Overly rich carburetion is easily detected by measuring the exhaust CO at idle and at 2500 RPM.

c. The CARCO MPC Tune-up Procedure

The objective of the CARCO MPC tune-up procedure was to "program" the mechanics to perform the tune-up in a manner which would provide the most cost-effective emission reductions and also reduce the engine to its practical MPC. The tune-up procedure is in five parts.

The first part of the MPC tune-up procedure consists of preventative maintenance. It is accomplished by removing any defects which could affect the diagnosis. This maintenance includes the inspection, repair or replacement of the exhaust manifold heat riser valve, the carburetor air filter, the PCV valve and the carburetor choke.

Part 2 of the procedure provides for an initial diagnosis and preliminary carburetor adjustments. The initial diagnosis includes an exhaust analysis with an infrared CO and HC instrument, a test with the secondary ignition tester and a quick oscilloscope analysis. This initial diagnosis can be easily completed by a trained and experienced mechanic within ten minutes. Over 90% of the time, this diagnosis will be sufficient to determine what repairs are needed, if any. Repair guidelines based upon HC and CO measurements given in Table 4. are used to determine when repairs should be made.

Mechanics using the MPC tune-up procedure are trained to quickly diagnose engine defects by the values of CO and HC at idle and 2500 RPM. This training is described in Section III.B.4.

Preliminary adjustments to the carburetor are performed at the idle to determine if the MPC goals of CO can be attained without engine roughness or lean misfire. If they cannot, then the idle mixture is richened up to the repair guideline. If the engine still will not idle at the higher repair guideline, then repair is required.

If the engine passes all the tests in Part 2, the mechanic checks the ignition point dwell and spark timing. The tune-up is complete.

If the engine fails the secondary ignition test, the mechanic completes Part 3. In Part 3, the spark plugs are inspected and replaced. The secondary ignition test is repeated. In over 90% of the cases, the engine will pass. The tune-up is complete after the timing and dwell are checked.

If the engine fails the second secondary ignition test in Part 3, a more thorough engine diagnosis is performed in Part 4. A power balance test is performed to isolate the cylinder or cylinders involved in the problem. This is performed by shorting out the cylinders one by one and recording the amount of speed drop. If the speed drop is zero or smaller than other cylinders, then there is a problem with that cylinder. Various diagnostic techniques combined with the HC and CO data previously gathered are used to find the problem.

The MPC tune-up procedure used by the ten Class A mechanics in this program is shown in the next three pages. Section I entitled "General Instructions" provides instructions for adjusting the carburetor, idle speed, spark timing and ignition dwell. The idle speed is usually adjusted to a higher speed than manufacturers' specifications for pre-1966 vehicles. This allows the idle CO to be adjusted leaner without encountering engine roughness or lean misfire. When spark timing adjustments are made, they are made to manufacturers' specifications plus nothing and minus 2^{o}. This places the normal adjustment tolerance on the low emission side because retarded timing reduces HC. Broad tolerances are given to dwell settings since it is not cost effective to change them if they are in an acceptable range and the timing is correct.

Repair limitations are given in Section IV because there is a point where added work to further reduce emissions is not cost effective.

TABLE 4

MPC TUNE-UP GOALS AND REPAIR GUIDELINES *

DOMESTIC CARS:

YEAR/TYPE	ENGINE CONDITION	MPC GOALS	REPAIR GUIDELINES	
		CO%	CO%	HC-PPM
Pre-1966	2500 Idle (a)	2 to 3	3.5 4.5	400 500
1966 thru 1969 Engine Mod.	2500 Idle (a)	1 to 2	2.5 3.0	300 400
1970	2500 Idle (a)	1	2.0 2.5	200 300
1966-1969 Cars With Air Pump Disconnected	2500 Idle (a)	3	3.0 4.5	400 500
FOREIGN CARS:				
Pre-1968	2500 Idle (b)	(c)	4.5 7.0	500 700
1968 - 1969 Engine Mod.	2500 Idle (b)	(b)	3.5 (d)	400 500
1970	2500 Idle (b)	(b)	3.0 (d)	300 400
1968 - 1970 Cars With Air Pump Disconnected	2500 Idle (b)	5	4.5 7.0	500 700

(a) 550 RPM IN DRIVE FOR AUTOMATIC TRANSMISSION CARS
650 RPM IN NEUTRAL FOR MANUAL TRANSMISSION CARS (USE MANUFACTURER'S SPECIFIED SPEED IF IT IS HIGHER).

(b) MANUFACTURER'S SPECIFICATIONS

(c) LEAN BEST IDLE

(d) 1% OVER MANUFACTURER'S SPECIFICATIONS

* Adjust dwell if out of the following limits:

V-8's	25 to 35 degrees
6's	30 to 50 degrees
4's	45 to 70 degrees

CARCO MPC TUNE-UP OPERATING PROCEDURE

I. GENERAL INSTRUCTIONS

A. Check exhaust manifold heat riser valve while engine is cold. Start car and warm up at fast idle.

B. Record adjustment and performance specifications in the boxes provided on the Tune-up Work Sheet while engine is warming up at fast idle for 20 minutes.

C. Perform pre-diagnosis maintenance as follows:

1. Check carburetor air filter cleanliness.
2. Measure pressure in crankcase. If positive pressure, measure flow rate of PCV valve and line into intake manifold. Check inlet to PCV valve for flow restriction. Also check for possible restriction in the hose and manifold inlet.
3. Check choke operation to be sure it opens freely.

D. Initial Diagnosis and Adjustments

1. Disconnect air hose on engines with air pumps and check air pump output.
2. Strive to adjust idle speed and mixture to MPC goals (Table I) with or without air cleaner filter.
3. Measure and record CO and HC at 2500 RPM.
4. Measure and record CO and HC at idle.
5. Compare CO and HC readings obtained above with MPC Repair Guidelines (Table I) and check timing if HC values are too high.
6. Test ignition system and spark plugs by first observing scope pattern and then performing the Fulton test. Make a visual inspection of the ignition system. If these ignition tests and the above performed CO/HC tests are acceptable, proceed to Step #10 below.
7. If engine fails Fulton test, inspect and replace spark plugs as required.

8. Repeat Fulton test. If the engine passes and CO/HC tests are acceptable, proceed to Step #10 below. If engine fails, perform cylinder power balance test to isolate the cylinder involved and diagnose other ignition system problems with oscilloscope and HC/CO meter. Repair or replace all defective ignition parts. Record parts replaced and comment on problems encountered.

9. If CO and HC emissions are above Repair Guidelines in Table I, refer to Table II for assistance in further diagnosis. Also refer to Repair Limitations in Section IV.

10. Check dwell and adjust if out of MPC specs.

11. Check basic spark timing and adjust as required.

12. Replace air cleaner (if removed) and make final carburetor adjustments. If CO and HC agree with Table I values, apply silicon cement to the idle mixture adjustment screws.

13. Perform final Fulton test and make sure all replaced parts are working.

14. The tune-up is complete.

II. ADJUSTMENT PROCEDURES

A. CARBURETOR MIXTURE AND SPEED

1. Balance idle mixture strength on multiple barrel carburetors.

2. Adjust idle jets to leanest setting possible without encountering lean misfire and undue engine roughness. Then richen by 0.25% CO.

   The leaner settings provide best pollution control; however, safety is the most important factor. The danger of a stalling car at an unsafe time (caused by too lean a mixture) must be avoided. The tendency to stall at leaner mixtures is lessened by the faster idle speed.

3. Strive to attain the values given in Table I.

B. SPARK TIMING

1. Retard as required for unleaded or low-lead fuels if owner desires.

2. Set to manufacturer's specifications--plus nothing - minus 2^{o}.

C. IGNITION DWELL

1. If points are not replaced, adjust dwell if out of the limits shown in Table I.

2. If points are replaced, set to manufacturer's specifications.

III. REPAIR AND MAINTENANCE PROCEDURES

1. Free-up heat riser valve by tapping shaft side to side and apply lubricant.

2. Free-up choke with carburetor cleaner as required.

3. Flow PCV valve and refer to charts for acceptable flow rate. If below specified value, replace PCV valve. If above specified value, clean valve with carburetor cleaner and replace.

IV. REPAIR LIMITATIONS*

1. Spend no more than five (5) minutes on heat riser valves.

2. Replace air cleaner when more than 50% of the light from a 100 watt light bulb is blocked by dirt.

3. Replace points only when diagnostic tests indicate a problem.

4. Do not remove intake manifolds or heads.

5. If CO and HC values are still too high after correctly performing the MPC procedures and reasonable repairs, further repairs will not be cost effective.

6. Check ignition wire terminal for corrosion and tight connection when replacing plugs.

7. Replace points if point contact is black or blue. Lubricate cam whenever a visual inspection of points is made.

8. If the diagnosis indicates sticking exhaust valves:

   a. Adjust valve lash if mechanical.

   b. Use valve oil/cleaner.

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* An MPC tune-up is one that provides the greatest amount of emission reductions for a minimum cost.

3. Selection and Upgrading of Class A Stations

a. Selection of Class A Stations

Ten (10) Class A stations were selected with the assistance of the California Highway Patrol. Prior to this selection, data on the number of stations of different types and the number of Class A mechanics working in each type of station was obtained. This data is tabulated in Table 5. below.

TABLE 5

CLASS A STATIONS AND MECHANICS
EAST LOS ANGELES AREA

TYPE OF CLASS A STATIONS	NO. OF LOCATIONS	NO. OF CLASS A MECHANICS	NO. OF CLASS A MECHANICS PER LOCATION	% OF TOTAL MECHANICS	% OF TOTAL LOCATION
Fleets	9	14	1.6	5.7	6.4
Service Stations	45	54	1.2	21.8	31.9
New Car Agencies	33	95	2.9	38.5	23.4
Independent Garages	40	57	1.4	23.1	28.4
Miscellaneous*	14	27	1.9	10.9	9.9
TOTAL	141	247		100.0	100.0

* The miscellaneous classification includes the following numbers of Class A mechanics working in the areas listed below:

8 - Training
5 - Butane Conversion
9 - Natural Gas Conversion
2 - Diagnostic Centers
2 - Muffler Shops
1 - Speedometer Service Shop

It is shown that:

(1) about 25% of the Class A stations are new car dealers and they employ about 40% of the Class A mechanics;

(2) about 30% of the Class A stations are service stations and they employ about 20% of the Class A mechanics;

(3) about 30% of the Class A stations are independent garages and they employ about 25% of the mechanics; and

(4) the balance (15%) of the stations are either fleet or miscellaneous operators.

The distribution of stations was selected on the basis of where Class A mechanics work. For example, new car dealers employ about 40% of the Class A mechanics. Therefore, four (4) of the ten (10) stations should be new car dealers.

Specific Class A station locations were obtained by selecting stations within a reasonable distance from the ARB test site and CARCO headquarters. Stations with only one Class A mechanic could not attend a week's training course without disrupting their business. Therefore, stations were selected with two or more Class A mechanics.

The miscellaneous type of Class A station was filled with a Shell Station which has a diagnostic center. The station appears to be representative of those planned by some oil companies for the future. The names and addresses of participating stations are listed in Table 6 . The Class A station owners and managers showed a high degree of interest in the program. Of 11 stations contacted, 10 agreed to participate. All 10 stations continued their participation throughout the program.

b. Upgrading of Class A Stations

The selected Class A stations were equipped with the following instruments which were then required by the California Highway Patrol:

Ignition analyzer-oscilloscope
Ammeter
Ohmmeter
Voltmeter
Tachometer
Vacuum gauge
Pressure gauge (0-10 psi)
Cam angle dwell meter
Ignition timing light
Engine exhaust combustion analyzer
Compression tester
Distributor advance tester

Most of these instruments are usually available in one unit, normally referred to as an engine analyzer.

The main problem with this equipment is that the engine exhaust combustion analyzers are not precise enough for adjusting engines to low emissions. These combustion analyzers only provide an approximation of the ratio of air to fuel and many times do not work properly. When working properly, they are useful in adjusting carburetors and can detect gross carburetion failures, such as a power enrichment valve that is stuck open. Hence, the replacement of the old air-fuel ratio analyzers with

TABLE 6

CLASS A STATIONS SELECTED

SERVICE STATIONS: 3

CHEVRON
8351 E. Washington Boulevard
Pico Rivera, California

UNION 76
4965 East Florence Avenue
Bell, California

TEXACO
10807 East Beverly Boulevard
Whittier, California

INDEPENDENT GARAGES: 2

Nisei Automotive Service
2428 West Beverly Boulevard
Montebello, California

Dusatko's Automotive Service
4825 East Florence Avenue
Bell, California

NEW CAR AGENCIES: 4

VOLKSWAGEN
Colome Motors, Inc.
1200 West Beverly Boulevard
Montebello, California

GENERAL MOTORS
Ostrom Chevrolet
310 Whittier Boulevard
Montebello, California

FORD
Montebello Motors
1112 West Whittier Boulevard
Montebello, California

CHRYSLER
East Los Angeles Dodge, Inc.
6575 Atlantic Boulevard
Los Angeles, California

MISCELLANEOUS

Pete's Shell Service
10742 East Beverly Boulevard
Whittier, California

more precise infrared (IR) analyzers was the major item in upgrading the Class A stations. These IR instruments measured both HC and CO and, therefore, were extremely valuable in the engine diagnostic process as well as being precise in engine adjustment procedures. A complete discussion of how these IR instruments were used in the diagnostic process is given in the next section. Five of the stations were supplied with GSM 300 instruments manufactured by Olson-Horiba, Inc. and five were supplied with ET-910 instruments manufactured by Sun Electric Corporation.

A secondary ignition tester previously referred to was also added to the Class A stations' instruments. This is a new instrument especially developed for this study. The primary purpose of this instrument was to determine when the spark plugs should be replaced. It was also useful in determining if there were any defects in the secondary ignition system which would prevent adequate electrical power from being supplied to the spark plugs.

A third item added to the Class A stations was a positive crankcase ventilation (PCV) system tester. It consists of a 0-30 inch of water vacuum gauge and the plumbing required to determine if a vacuum existed in the crankcase. If it did, then the PCV valve flow was greater than the flow of blow-by gases passing the piston rings and the PCV system operation was acceptable.

If there was no vacuum in the crankcase, then either the PCV valve or lines were plugged or the engine had excessive blow-by. In order to establish which was the problem, a fourth item was added to the Class A stations' instruments. It was a flow meter for measuring the flow rate of blow-by gases through the PCV valve and lines. If the flow through the PCV valve and lines was within manufacturer's specifications, then the problem was excessive blow-by. If the flow was below the specifications, then the PCV valve and/or lines were plugged. This PCV valve flow meter can be also used to measure the amount of blow-by gases.

In summary, the ten Class A stations were upgraded to accomplish MPC tune-ups by adding the following four instruments to the Class A stations:

HC and CO Infrared Exhaust Analyzer
Secondary Ignition Tester
PCV System Tester
PCV Valve Flow Meter

4. Training of Class A Mechanics

Each of the owners of the ten Class A stations previously discussed sent a Class A mechanic to a 40 hour (one week) training course. The owners and service managers were requested to send their average mechanic--not their best or their least qualified. A representative cross-section of mechanics attended the course. The length of time that the mechanics had their Class A licenses ranged from three months to ten years. The average was four years. The ages of the mechanics ranged from 20 to 50 years and the average was 32 years.

a. Training Course Organization

The training course was held Monday through Friday with four hour sessions in the morning and in the afternoon. Approximately one-half of the time was spent in a garage-type laboratory where each mechanic was given "hands-on" training in the areas of operating instruments and performing the diagnostic portion of the MPC tune-ups. The itinerary for the course is given below:

MONDAY	A. M.	The Automobile and Air Pollution in California
	P. M.	The MPC Tune-up Approach
TUESDAY	A. M.	Exhaust Carbon Monoxide and Engine Carburetion
	P. M.	Carburetor Circuits, Adjustments and Repair Guidelines
WEDNESDAY	A. M.	Exhaust Hydrocarbons and Engine Ignition/Exhaust Valves
	P. M.	Diagnosis with HC and Oscilloscope Measurements
THURSDAY	A. M.	The MPC Tune-up Procedure
	P. M.	Cost-Effective Repairs and Preventative Maintenance
FRIDAY	A. M.	Cost-Effective Repairs and Preventative Maintenance
	P. M.	Review and Questions on MPC Tune-up Procedure

In the Monday A. M. session, the mechanics were introduced to the types of pollutants emitted from engines and how they affect the quality of the air. They learned the types of poor engine maintenance which affects emissions and what engine defects cause which pollutants to increase. The objective of this session was to provide the background needed for the mechanic to understand how exhaust emissions relate to engine operation.

An introduction to the MPC tune-up approach of reducing automobile emissions was given in the Monday P. M. session. This was done to sell them on the importance of their role in air pollution control. It also gave them an idea on what they could expect in the following sessions and how to relate their training to the end job of actually performing MPC tune-ups.

The Tuesday A. M. session was devoted to teaching the mechanics how CO exhaust emissions relate to carburetion. They were taught how to operate the IR CO instruments and how to diagnose various malfunctions from the data obtained.

The Tuesday P. M. session provided a review of the basic circuits in a carburetor and how they relate to the values of CO measured at different engine speeds. The mechanics were taught how to perform low emission carburetor adjustments with a CO meter. They were also instructed on how to measure CO at different speeds and compare these values with guidelines to decide if the carburetor needs repair.

In the Wednesday A. M. session, the mechanics were taught how to measure HC in the exhaust and how to relate these measurements with engine defects. In the Wednesday P. M. session, they were taught how to use the HC meter and oscilloscope together to provide a rapid diagnosis of defects in the ignition system and/or exhaust valves. They were given a basic understanding on the relationship between incomplete combustion and HC emissions. Instructions were also provided to show how the CO and HC measurements could be used together at various engine speeds to detect lean misfires.

The MPC tune-up procedure was reviewed in the Thursday A. M. session. Information learned on how to diagnose and adjust engines with HC and CO measurements was applied on several different vehicles. The class was divided into three groups, and each mechanic performed the diagnostic and adjustment portions of the MPC tune-up procedure.

The Thursday P. M. and Friday A. M. sessions were used to teach techniques for performing cost-effective repairs and preventative maintenance. These were very important sessions because some engines emit HC and CO at levels above the repair guidelines even though conventional cost-effective repairs were completed. In these cases, the mechanics must be given background information to guide them in a decision on when to stop making repairs. The diagnoses of engines with difficult problems to detect were also discussed.

The Friday P. M. session was a review of all of the new tune-up principles and techniques introduced in the course. The session concluded with a question and answer period on the MPC tune-up procedure and potential problems which may arise.

b. Training Course Objectives

Four basic objectives of the CARCO MPC tune-up training course and actions taken to carry them out are given below in the outline-type format.

---

1. Motivate mechanics to expertly perform low-pollution tune-ups by:

   a. Providing a background on how the automobile is involved in the air pollution problem.

   b. Describing the pollutants in automobile exhaust and explaining how they are produced.

   c. Informing them of the great need for upgraded Class A mechanics to reduce these pollutants by diagnosis, repair and adjustments.

d. Asking them to accept the professional challenge and responsibilities involved in reducing emissions of used cars and maintaining low emissions of future cars.

2. Teach mechanics to relate excessive CO and HC emissions to engine malfunctions as the first important step in diagnosis by:

   a. Teaching them how to measure CO and HC emissions.

   b. Showing how carburetor malfunctions affect CO and how problems with different carburetor circuits can be detected by operating the engine at different speeds.

   c. Informing them of the engine malfunctions which affect HC emissions and showing how HC measurements at various speeds can be used to isolate problems.

3. Train mechanics to perform the CARCO MPC tune-up procedure in a precise and predictable manner by:

   a. Providing a detailed step by step procedure and being certain that they understand the need for each step and how to accomplish it.

   b. Programming the mechanics in diagnostic actions, repair decisions and adjustment operations by providing specific instructions and specifications for repair and adjustments.

   c. Minimizing instructions which leave difficult subjective and general decisions to the mechanics.

4. Train mechanics to perform CARCO MPC tune-ups in the most cost-effective manner by:

   a. Teaching them to follow a procedure and use a work sheet which are:

      (1) simple as possible;

      (2) designed to avoid repeated motions;

      (3) arranged to minimize interrelated effects of carburetion and ignition on data gathered;

      (4) designed to quickly complete engines which may only require a simple diagnosis and adjustments and, at the same time, provide basic data on engines requiring more extensive diagnoses and repairs.

   b. Instructing on the use of a secondary ignition tester for rapidly detecting present and impending spark plug and ignition problems.

c. Showing them how to quickly scan an oscilloscope to detect ignition problems related to emission increases.

d. Providing guidelines for repair decisions.

e. Teaching techniques for low-cost repair of defects.

---

c. Engine Diagnoses through Exhaust Gas Analysis

The most important part of the training program was to show mechanics how to diagnose engines by simply messuring HC and CO at idle and 2500 RPM. Problems with most engines can be detected by a quick inspection of these four values. A goal of the training course was to have the mechanics immediately obtain these values as the primary basis for any diagnosis. If they needed further information to make or confirm their diagnoses, they should seek that secondly. It requires a considerable amount of training and on-the-job experience to divert a mechanic's diagnostic habits away from conventional procedures and convert him to first think about exhaust emissions. Once this conversion occurs, his diagnostic speed and accuracy is significantly increased.

Examples of HC and CO values at idle and 2500 RPM for common engine malfunctions are given in Table 7. These samples are grouped into two classifications: high CO emissions and high HC emissions. All of the engine malfunctions due to excessive CO are related to improper carburetion. Engine malfunctions related to excessive HC emissions include defects in ignition system, the exhaust valves and lean carburetion. Common causes of excessive exhaust emissions are given in Table 8. Both of the above tables were prepared for the mechanics as on-the-job reference material.

d. Cost-Effectiveness Repairs

The mechanics were taught cost-effective repair techniques and given repair limitations. Examples of cost-effective repair techniques are:

(1) If the carburetor is operating too rich, bring the engine up to about 2500 RPM without the air cleaner. Then cover the carburetor inlet with a shop towel until it nearly stalls. Repeat this process several times. This technique forces gasoline into the air bleed passages of the carburetor. When a carburetor is operating too rich, these air passages are often plugged up and can be cleaned out by this process.

(2) If the carburetor idle adjustment screws have no effect or if the idle mixture is too rich or too lean and cannot be

TABLE 7

GUIDE FOR ENGINE DIAGNOSIS THROUGH EXHAUST GAS ANALYSIS*

HIGH CO EMISSIONS

CO		HC		ENGINE MALFUNCTION
IDLE	2500 RPM	IDLE	2500 RPM	
High	Normal	Slightly Above Normal	Normal	Idle Jets too Rich
High	Above Normal	Slightly Above Normal	Normal	Plugged PCV System
High	Slightly Above Normal	Slightly Above Normal	Normal	Plugged Air Bleed in Idle Circuit
High	High	Slightly Above Normal	Slightly Above Normal	Partially Closed Choke
Slightly Above Normal	High	Normal	Normal	Plugged Air Cleaner
Normal	High	Normal	Slightly Above Normal	Oversized Main Jets
Normal	High	Normal	Slightly Above Normal	Leaking Power Jet
Normal or Above Normal	Above Normal	Normal	Normal	High Carburetor Float Level
HIGH HC EMISSIONS				
Normal	Normal	Very High	Very High	Ignition System Misfire
Normal	Normal	Above Normal	Above Normal	Advanced Ignition Timing
Slightly Below Normal	Usually Normal	High	Above Normal	Intake Manifold Leak
Normal	Normal	High	Above Normal	Leaking Exhaust Valves
Low to High	Normal	Above Normal	Normal	Unbalanced Carburetor Idle

TABLE 8

CAUSES OF EXCESSIVE EXHAUST EMISSIONS

EXCESSIVE CO IN THE EXHAUST RESULTS FROM A RICH CARBURETOR CONDITION. THIS CONDITION CAN BE CAUSED BY:

1. IMPROPERLY ADJUSTED IDLE SCREWS;
2. A PLUGGED AIR CLEANER;
3. A DEFECTIVE POWER ENRICHMENT JET;
4. PLUGGED AIR BLEEDS;
5. PLUGGED PCV VALVE OR SYSTEM;
6. OVERSIZED OR DRILLED MAIN JETS;
7. HIGH CARBURETOR FLOAT LEVEL;
8. PARTIALLY CLOSED CHOKE; AND
9. OR OTHER CARBURETOR DEFECTS.

EXCESSIVE HC IN THE EXHAUST RESULTS FROM INCOMPLETE COMBUSTION OF THE GASOLINE. THIS CONDITION CAN BE CAUSED BY:

1. MISFIRE DUE TO IGNITION SYSTEM FAILURE (SPARK PLUGS OR WIRING);
2. MISFIRE FROM TOO LEAN A MIXTURE (CARBURETOR PROBLEMS OR INTAKE MANIFOLD LEAKAGE);
3. BURNED OR STICKING EXHAUST VALVES;
4. OVER-ADVANCED SPARK TIMING; AND
5. EXCESSIVELY RICH CARBURETION.

corrected with the idle screws, remove the screws and blow through the holes with compressed air and/or carburetor cleaner.

(3) If the carburetor throttle body and other carburetor parts like the choke mechanism are affected by deposits, use a spray-type carburetor (aerosol can) cleaner to remove deposits.

Repair limitations are given in the MPC Tune-up Procedure in the previous section, III,B,2.

e. An abbreviated one-page work sheet was designed to speed up the tune-up work. This sheet is shown in Table 9 . The sheet is arranged in the same sequence as the tune-up procedure. It was used during the training course as a guide in following the procedure and for recording emission data for the diagnostic process.

While the engines were warming up at fast idle, the mechanics were instructed to fill in the rectangles outlined with wide black lines. This provides them with engine adjustment specifications, MPC emission goals and MPC emission repair guidelines. Gathering all of this information at one time and placing it on one sheet for easy reference saves time.

After the trained mechanic performs a few MPC tune-ups, the abbreviated work sheet, a book of engine tune-up specifications and the MPC guidelines in Table 4 are all he needs for guidance and documentation.

5. Selection and Solicitation of the Test Vehicles

a. Vehicle Selection

A 300 car sample was selected to be representative of the 1957 through 1970 passenger car population in California. This 300 car sample is shown in Table D-1 in Appendix D.

b. Vehicle Solicitation

The solicitation of test vehicles was a much more difficult task than estimated. The major reason for this was probably because owners were not specifically told what would be done to their vehicles. An offer of a free tune-up was specifically avoided so that the sample would not have an abnormal amount of vehicles needing a tune-up.

The first solicitation approach was to obtain a computer print-out which identified 12,000 vehicles in the Montebello area. Three vehicles were randomly selected for each vehicle type needed. A personalized letter shown in Figure D-1 in Appendix D was sent out to each potential participant. The intent of this letter was to generate enough interest in the program so that owners would participate. Their participation

TABLE 9

CAR # ______________ LICENSE # ___________________ ODOMETER __________________

CARCO MPC TUNE-UP WORK SHEET

PART I: MAINTENANCE

A. Heat Riser: Free [ ] Open [ ] Closed [ ] None [ ]

B. Air Cleaner: OK [ ] Replace [ ] Cleaned [ ]

C. Crankcase Pressure: Pass [ ] Fail [ ] Replaced [ ]

PART II: INITIAL DIAGNOSIS AND ADJUSTMENTS (ENGINE WARMED UP)

A. Air Pump Output: Pass [ ] Fail [ ] None [ ]

B. MPC Idle Speed and Mixture Goals: Speed [ ] % CO [ ]

ENGINE CONDITION	INITIAL		FINAL	
	W/FILTER [ ]	W/O FILTER [ ]	W/FILTER	
	CO	HC	CO	HC
2500 RPM				
MPC REPAIR GUIDELINE			X	X
MPC IDLE				
MPC REPAIR GUIDELINE			X	X

C. Scope Pattern: Normal [ ] Abnormal [ ]

D. Fulton Tester: Pass [ ] Fail [ ]

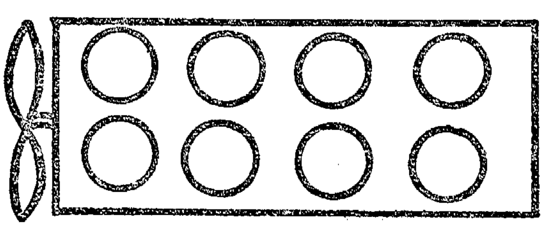
E. Dwell: MPC Spec. [ ] Basic Timing, Mfgr's. Spec. [ ]

PART III: IGNITION SYSTEM REPAIR (FAILED FULTON TEST)

A. Inspect and Replace Spark Plugs [ ]

B. Repeat Fulton Test Pass [ ] Fail [ ]

PART IV: FAILED SECOND FULTON TEST AND/OR HC/CO TEST (ISOLATE CYLINDERS INVOLVED)



Scope Cyl. #	1	2	3	4	5	6	7	8
Drop								
Eng. Cyl. #	1							

PART V: FINAL DIAGNOSIS AND COMMENTS: ______________________________

____

____

CARCO FORM #8

would minimize the number of vehicles entering the program because their engines required work. A self-address, prepaid postcard (Figure D-2 in Appendix D) was included with the letter for return by interested vehicle owners.

The public's response to this letter was poor. Of the 450 letters sent to vehicle owners, 14 postcards were returned of interested persons. Of these 14 postcards, seven of these vehicles could not be used in the program. Thirty-seven (37) letters were returned because no forwarding address was available.

Follow-up calls were then made to vehicle owners who were sent the letters. Of the 76 calls made:

(1) 49 owners had either moved or did not have listed telephones;

(2) 24 were not interested in participating; and

(3) 3 were interested and mailed the postcards for their participation at a later date.

The net result of solicitation by mail and telephone contact resulted in placing ten vehicles on test.

Other methods of solicitation subsequently used were:

(1) newspaper advertisements;

(2) notices on bulletin boards of small businesses;

(3) an article in the Newsletter of the City of Commerce's Chamber of Commerce; and

(4) word of mouth.

A typical example of a newspaper advertisement is given in Figure D-3 in Appendix D.

6. Test Results

This section of the report discusses emission, fuel consumption, and driveability test results obtained from the vehicles selected for MPC tune-ups. The results are presented under three headings entitled: Rejected Vehicles, After MPC Tune-up, and After Six Months of Service.

a. Rejected Vehicles

The scope of the MPC tune-up program excluded engines with inoperative cylinders because of defective valves. These vehicles were rejected after the "as received" emission tests by the Class A mechanics. When the mechanic's diagnosis of a vehicle revealed a burned or defective valve, he was instructed to reject the vehicle. This process was useful in establishing how many vehicles have defective valves and what their level of emissions are compared to other vehicles.

A total of nine vehicles was rejected from the program. Eight were pre-1966 vehicles without exhaust emission controls provided by the original manufacturer (hereafter called uncontrolled vehicles). One was a post-1965 vehicle with exhaust emission controls by the original manufacturer (hereafter called a controlled vehicle). The 300 vehicle population tested consisted of 159 uncontrolled vehicles and 141 controlled vehicles. Data on these vehicles are given in Table 10.

The emission tests on three of the nine vehicles showed that valve burning was not probably present. This was true even though the diagnoses of two of the three vehicles showed that the compression on some cylinders was low. These engines probably had valves that were sticking open at idle but were closing under power.

This data shows that the percentage of pre-1966 vehicles with burned exhaust valves was about 4%. The percentage of 1966-1970 vehicles with burned exhaust valves was less than 1%. It is interesting to note that the average level of HC emissions from the uncontrolled vehicles with burned valves was only about twice as much as the average of uncontrolled vehicles without burned valves. If the two vehicles referred to above with low emissions are excluded from this group, the average emissions for the other six equals 19.9 grams per mile. The average "as received" HC emissions for the group of 159 uncontrolled vehicles was 10.8 grama per mile. This shows that HC emissions increased by about 9 grams per mile due to valve burning. This HC emission increase is highly dependent upon the severity of the valve damage and the number of cylinders involved. Usually burned valves are detected and repaired when a rough idle develops.

The above data was used to calculate the increase in vehicle HC emissions due to exhaust valve burning. The calculation is given in Table D-2 in Appendix D. It shows that burned exhaust valves are responsible for about 2.8% of the vehicle HC exhaust emissions. This assumes that the vehicle population consists of pre-1971 vehicles and valve burning in 1966-1970 vehicles is 1/2%. If the percentage of vehicles with burned valves remains the same in the future, the total quantity of HC emissions exhausted due to burned valves will remain the same. However, the percentage of the total vehicle HC emissions due to burned valves will increase because an added 9 grams per mile on a lower emission vehicle become a greater percentage of that vehicle's HC emissions.

TABLE 10

REJECTED VEHICLES - BURNED VALVES

I. UNCONTROLLED VEHICLES

CAR #	YEAR & MAKE	HC GMS/MI	ODOMETER MILES	MECHANICS' COMMENTS
A003	'63 Mercury	16.0	114,001	Dead cylinder
A023	'62 Cadillac	32.10	124,408	Collapsed valve lifters or burned valves
A064	'65 Ford	26.20	81,327	No compression on No. 8 cylinder
A067	'64 Ford	17.45	91,094	Zero compression on No. 3 cylinder
A088	'61 Mercury	6.26	87,925	Two cylinders--no compression
B009	'64 Ford	6.77	81,005	Burned valve
B071	'58 Chevrolet	9.88	124,822	Low compression--one cylinder (35 psi)
A163	'61 Cadillac	17.5	Defective	Burned valves
	AVERAGE	16.5	100,654	

II. CONTROLLED VEHICLES

B096	'69 Olds.	4.70	41,142	90 psi compression in No. 1 cylinder

The contribution of burned or sticking valves to the total vehicle HC emissions discussed above is lower than expected. Possible reasons for this are as follows:

(1) Burned and sticky valves result in a rough idle which is easily detected by vehicle owners. Therefore, repairs may be made before high emission levels are reached.

(2) Engine operation at speeds faster than idle give the defective valves less time to leak.

(3) Engine operation under load tends to seat valves that stick open at idle.

(4) The fuel may burn more completely in the cylinder and in the exhaust ports than expected.

Two owners of vehicles rejected decided to repair the exhaust valves in their engines in order to participate in the program. The HC and CO emissions for these vehicles before and after the valve work are given in Table 11 below.

TABLE 11

VEHICLES WITH VALVE REPAIR AFTER REJECTION

CAR #	VEHICLE YEAR AND MAKE	EMISSIONS - GM/MI BEFORE VALVE WORK		EMISSIONS - GM/MI AFTER VALVE WORK	
		HC	CO	HC	CO
B009	1964 Ford	6.77	58.2	4.76	99.9
A163	1961 Cadillac	17.5	124.8	5.50	109.0
	AVERAGE:	12.1	91.5	5.13	104.5

The 1974 Ford probably had sticking valves instead of burned valves because the HC emissions under load were normal. The valve work on the vehicle only decreased the HC emissions slightly. The 1961 Cadillac probably had reasonably severe valve burning because the valve work reduced HC emissions by a factor of 3.

b. After MPC Tune-up

The summary of the test results on 300 vehicles given MPC tune-ups is shown in Table 12. Sizable emission reductions were obtained on vehicles with and without factory controls. Larger HC, CO, and fuel consumption reductions were obtained with the older uncontrolled vehicles because they were adjusted leaner than manufacturer's specifications and were more poorly maintained. As expected, the NO_x emission increased due to the leaning of the air-fuel mixture.

The average costs for the MPC tune-ups on uncontrolled and controlled vehicles were both low. The MPC tune-up is particularly cost-effective on the uncontrolled vehicles when the cost savings in fuel consumption and large HC reductions are considered.

The change in vehicle driveability due to the MPC tune-up was satisfactory. The owners were the most critical on a questionnaire mailed back immediately after the tune-up. At the two week interview, 54% of the owners said the vehicle performed better, 31% said there was no change, and only 15% said the vehicle performed worse. Tests by the CARCO technician showed that the vehicle performance was better on 54%, the same on 16% and worse on 29%. These results are encouraging because the lean tuning reduces the performance of many vehicles.

It would appear that the 15% of the owners reporting worse performance could be a serious defect in the MPC procedure. This is probably not true because driveability results on 50 vehicles equipped with dummy VSAD kits showed that 48% of the owners thought that the vehicles drove worse. These dummy kits did not disconnect the vacuum spark advance and no other work was done to the engines. This shows that vehicle owners become very critical when asked about their vehicle's performance after some work was presumably done to the engine.

Driveability tests performed by CARCO technicians showed that the test fleet had 830 demerits before the MPC tune-ups and 470 after. Further information on owner acceptance of MPC tune-ups was obtained after six months. This information is discussed in the next section.

The 300 vehicle test fleet was comprised of two groups of vehicles. One hundred (100) of these vehicles called "B" vehicles were given MPC tune-ups and two weeks later had VSAD kits installed. The other 200 vehicles were given only MPC tune-ups.

Table 13 summarizes changes in emissions, fuel consumption and driveability of "A" and "B" vehicles. The average costs for the tune-ups are also given. It is interesting to note that almost all of the test and driveability results for these two groups of vehicles was nearly the same for the first two weeks. These results show that the two similar groups (selected to both be representative of 1955-1970 vehicles) were apparently large enough to offset individual vehicle differences.

TABLE 12

SUMMARY OF TEST RESULTS--BEFORE AND AFTER MPC TUNE-UPS

EMISSIONS - GRAMS/MILE

	Before	After	% Reduction
Controlled Vehicles			
HC	4.82	3.55	26.3
CO	45.9	29.5	35.7
NOX	4.28	4.47	⟨4.4⟩
Uncontrolled Vehicles			
HC	10.8	6.22	42.4
CO	83.8	54.6	34.9
NOX	3.21	3.38	⟨5.3⟩
Composite			
HC	7.96	4.94	37.9
CO	66.0	42.8	35.2
NOX	3.70	3.89	⟨5.1⟩

COSTS - AVERAGE

141 Controlled Vehicles...........$26.46
159 Uncontrolled Vehicles.........$28.66
300 Total Vehicles................$27.47

FUEL CONSUMPTION - % REDUCTION

Controlled Vehicles...............2.7%
Uncontrolled Vehicles.............6.8%
Composite.........................4.9%

DRIVEABILITY

Owner Mail-Back Questionnaire	
Better - % of Vehicles	43
Worse - % of Vehicles	30
No Change - % of Vehicles	27
Owner Interview After Two Weeks	
Better - % of Vehicles	54
Worse - % of Vehicles	15
No Change - % of Vehicles	31
CARCO Drivers After MPC	
Better - % of Vehicles	55
Worse - % of Vehicles	29
No Change - % of Vehicles	16

TABLE 13

Data Summary for 200 "A" Cars and 100 "B" Cars

Before and After MPC Tune-Ups

	"A" Cars	"B" Cars
Hydrocarbon Emission		
Before - Grams / Mile	7.89	8.10
After - Grams / Mile	5.05	4.80
% Change	-37.9	-39.6
Carbon Monoxide Emission		
Before - Grams / Mile	62.5	72.1
After - Grams / Mile	41.1	45.4
% Change	-34.2	-37.1
Oxides of Nitrogen Emission		
Before - Grams / Mile	3.70	3.71
After - Grams / Mile	3.88	3.94
% Change	+3.19	+6.2
Average Cost - Dollars	27.10	28.11
Fuel Consumption = Change - %	-5.19	-4.0
Driveability		
Owner Mail - Back Questionnaire		
Better - No. of Cars / %	86/43	44/44
Worse - No. of Cars / %	61/30	29/29
No Change - No. of Cars / %	53/27	27/27
Owner Interview After 2 Weeks		
Better - No. of Cars / %	107/54	55/55
Worse - No. of Cars / %	32/16	12/12
No Change - No. of Cars / %	61/30	33/33
CARCO Drivers After MPC		
Better - No. of Cars / %	115/58	49/49
Worse - No. of Cars / %	57/28	30/30
No Change - No. of Cars / %	28/14	21/21

The good agreement between the emission levels of the "as received" vehicles of both groups, the assignment of "B" vehicles early in the program and the changes in soliciting techniques throughout the program indicate that these vehicles are probably representative of those from a 15 mile radius of Montebello, California. These "as received" emissions are higher than those from vehicles tested in a study (1) by Northrop Corporation conducted two years earlier. Possible reasons for this are:

(1) the vehicles in this study were emission tested first and only rejected when the Class A mechanics reported dead cylinders and

(2) the population of vehicles in this study are two years older and probably in poorer condition.

Summaries of information and performance data for each of the 10 Class A stations and mechanics are given in Tables 14 and 15. This data was tabulated and analyzed in an attempt to determine if there are any relationships between:

(a) station type

(b) the mechanic's experience, age and class grade

(c) station specialty

(d) the effectiveness and cost of the MPC tune-up

A cost-effectiveness shown in Table 14 was calculated by dividing the station's average cost of tune-ups by the sum of the percent reductions in HC and CO.

The only parameters producing a possible correlation are the cost effectiveness versus the years of mechanic experience. This relationship is shown in Figure 1. and is the reverse of what might be expected. The men with fewer number of years working as Class A mechanics produced the most cost-effective tune-ups. This is not due to the fact that the older men receive a higher rate of pay because greater emission reductions were the primary factor. Variables such as differences in vehicles, labor rates, the condition of vehicles, working conditions, and business practices tend to obscure the talents and traits of individual mechanics.

Common traits of the younger and less experienced mechanics were that they appeared more competitive and motivated toward reducing emissions. Motivation, management support, and low emission tune-up training appear to be essential in controlling used vehicle exhaust emissions.

TABLE 14

DATA ON 10 CLASS A STATIONS AND CLASS A MECHANICS

Station Number	Type of Station	Specialty	Experience* and Age of Class A Mechanic -years	Training Class - Grade	Emission Reductions %- HC/CO After MPC	Cost-Average per car -Dollars	Cost Effectiveness $/ %reductions**	Owner Complaints Due to Mechanic Error	No. of Cars Tuned
1	Independent Garage	None	½ / 20	92	51.0/34.9	29.65	.35	5	35
2	Union Station	None	2 / 23	88	41.2/46.8	26.67	.30	2	32
3	Dodge Dealer	Chrysler Products	7 / 46	83	54.2/40.3	24.63	.26	5	22
4	Independent Garage	Imported Cars	4 / 24	88	22.6/25.7	20.42	.42	2	32
5	V.W. Dealer	V.W.'s	1 / 23	71	32.2/22.0	12.94	.24	0	25
6	Ford Dealer	Ford Products	10 / 50	91	21.9/18.9	27.10	.66	3	30
7	Chevrolet Dealer	G.M. Products	6 / 29	88	26.4/31.6	36.49	.63	1	30
8	Texaco Station	None	¼ / 23	87	47.4/29.4	27.75	.36	1	31
9	Shell Station	None	3 / 27	97	41.3/51.2	33.57	.36	3	33
10	Chevron Station	None	5 / 50	92	21.8/40.9	31.49	.50	3	30

*Working as Class A Mechanic
** Average Cost divided by the sum of the HC & CO reductions in percent.

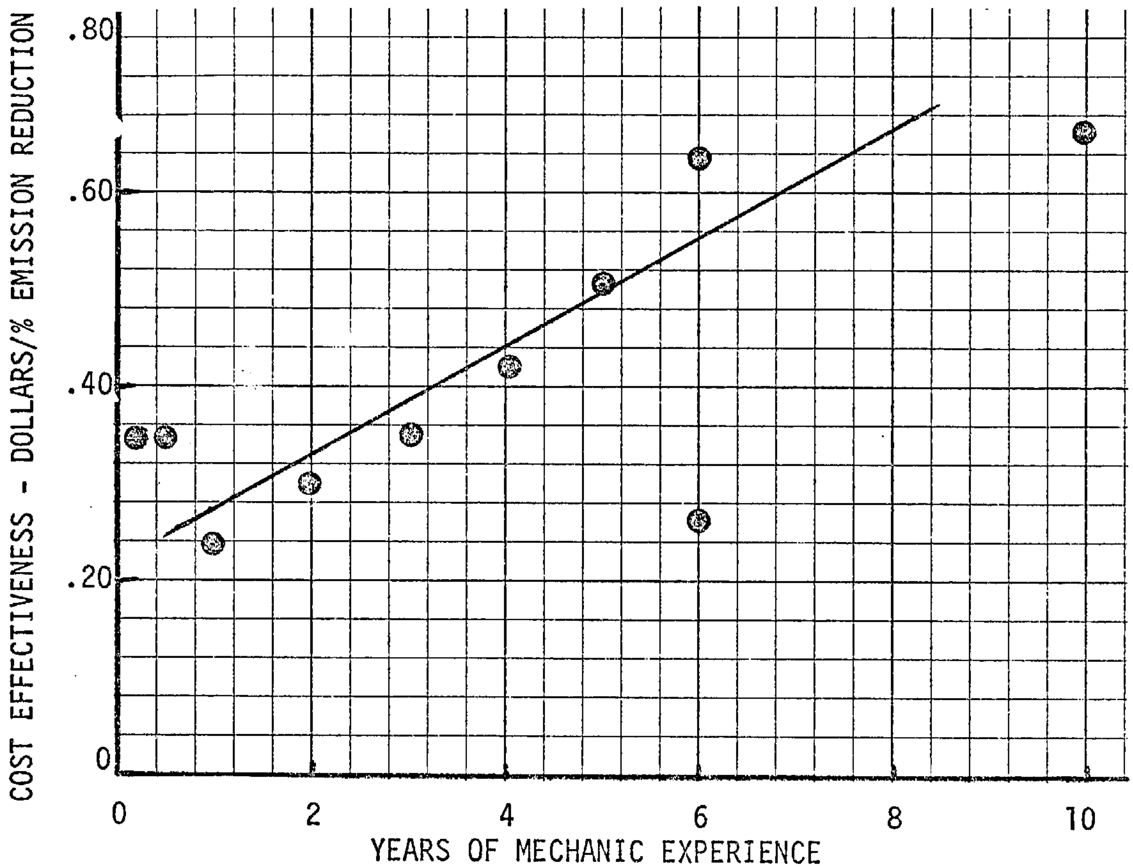
TABLE 15

MPC TUNE-UP RESULTS FOR EACH CLASS A STATION

Station Number	EMISSION DECREASE %			AVERAGE COST – $			Fuel Consumption Decrease %	Idle CO % - as received	Complaints due to Mechanics Error
	HC	CO	NO	Total	Labor	Parts			
1.	51.0	34.9	(5.3)	29.65	13.29	16.53	2.5	6.98	5
2.	41.2	46.8	(8.8)	26.67	14.41	12.58	5.2	5.65	2
3.	54.2	40.3	(17.0)	24.63	14.32	15.42	9.1	5.18	5
4.	22.6	25.7	(1.5)	20.42	13.60	9.42	6.5	3.88	2
5.	32.2	22.0	(5.4)	12.94	8.57	7.40	4.5	4.98	0
6.	21.9	18.9	(3.2)	27.10	16.52	11.08	6.3	5.13	3
7.	26.4	31.6	(0.8)	36.49	21.66	13.69	3.0	4.88	1
8.	47.4	29.4	(5.6)	27.75	14.60	12.90	4.8	4.80	1
9.	41.3	51.2	(1.0)	33.57	18.01	14.79	0.7	5.11	3
10.	21.8	40.9	(0.5)	31.49	13.46	20.08	6.8	6.10	3

FIGURE 1

CORRELATION BETWEEN MECHANIC EXPERIENCE AND THE COST EFFECTIVENESS OF THE MPC TUNE-UP



c. Analysis of Initial Emission Reductions

The original concept of the MPC tune-up approach to reducing used vehicle emissions was that <u>every</u> vehicle should be diagnosed, repaired and adjusted to its minimum pollution capability. The test data on the initial effectiveness of the MPC tune-up indicate that perhaps every vehicle should not be adjusted and/or repaired because 33% of the controlled vehicles and 26% of the uncontrolled vehicles increased in hydrocarbons after the tune-up. Twenty-two percent (22%) of the controlled vehicles and 13% of the uncontrolled vehicles increased in carbon monoxide after the tune-up.

Most of the vehicles that increased in emissions had low emissions prior to the tune-up work. The average controlled vehicle that increased in HC was below about 2.5 grams per mile compared to 4.8 grams per mile for the fleet. The average uncontrolled vehicle that increased HC was below about 5.0 grams per mile compared to 10.8 for the total fleet. The average controlled vehicle that increases in CO was below about 27 grams per mile compared to 45.9 grams per mile for the total fleet. The average uncontrolled vehicle that increased in CO was below about 44 grams per mile compared to 83.8 grams per mile for the total fleet.

The above data indicates that vehicles with emission levels of one-half the average of their group should not be tuned up. This is approximately true for both HC and CO emissions and both groups of vehicles.

These emission increases may have been due to improper repairs or adjustments. Improper adjustments could have consisted of:

(1) excessive leaning resulting in lean misfires

(2) too lean or too rich carburetor adjustments due to faulty instruments

(3) mechanic errors

(4) advancing the spark timing of engines which were overly retarded.

Thirty percent (30%) of the total fleet (controlled plus uncontrolled vehicles) increased in HC after tune-ups. If these vehicles were not tuned, 5.3% greater HC reductions would have been attained (43.2% reduction rather than 37.9%). The difficulty in attaining this added reduction is determining how to isolate the vehicles that should not be tuned--short of running an expensive 7-mode test on every vehicle. Even with the 7-mode data, a problem exists on how to determine which ones would increase in HC if tuned. This could be approximated by rejecting 30% of the lowest emitters, but considerable overlap occurred where some of the lower emitters decreased and others increased in HC emissions.

A study of the test data was made to determine the amount of emission reductions attainable if the top 10%, 25%, and 50% emitters were rejected by the 7-mode emission test or its equivalent. The results are given in Tables 16. and 17. It is important to note that the reductions calculated are those for the group of vehicles immediately after tune-up. The advisability of rejecting a percentage of the vehicles for MPC tune-ups rather than tuning all vehicles will depend on how much the total fleet emissions increase from the vehicles not rejected and not given preventative maintenance. This subject is discussed in further detail in the next section.

In Table 16, it is shown that a significant HC reduction is attained by only rejecting and repairing 10% of the vehicles. The cost effectiveness is the highest of any other percentages. This is true because ignition misfires increase HC emissions by an order of magnitude. They are, therefore, included in the top 10% emitters and are inexpensive to repair. The rejection and repair of 50% of the vehicles produce about the same amount of emission reductions as for all vehicles. This is true because some of the lower emitting vehicles increase in emissions due to the tune-up, and the greatest emission reductions are gained from tuning the highest emitters.

TABLE 16

HC EMISSION REDUCTIONS BY TUNING
VARIOUS PERCENTAGES OF VEHICLES

PERCENTAGE OF VEHICLES	REDUCTION %	HC - GRAMS/MILE		AVG. COST - $/ALL VEHICLES		COST EFFECTIVENESS $/VEHICLE/GMS./MI.
		BEFORE MPC	AFTER MPC	ALL VEHICLES	REJECTED VEHICLES *	
CONTROLLED						
100	26.3	4.82	3.55	26.46	-----	.15
10	18.4	13.5	4.52	-----	8.54	.068
25	24.8	9.64	4.81	-----	13.69	.081
50	27.5	7.13	4.45	-----	21.25	.114
UNCONTROLLED						
100	42.4	10.8	6.22	28.66	-----	.039
10	24.7	32.9	6.18	-----	9.40	.022
25	34.0	22.1	7.43	-----	13.99	.024
50	41.1	15.8	6.92	-----	22.21	.031

* Assumes a $5 fee for an inspection test on all vehicles.
Rejected vehicles are retested once.

TABLE 17

CO EMISSION REDUCTIONS BY TUNING
VARIOUS PERCENTAGES OF VEHICLES

PERCENTAGE OF VEHICLES	REDUCTION %	CO - GRAMS/MILE		AVG. COST - $/ALL VEHICLES		COST EFFECTIVENESS $/VEHICLE/GMS./MI.
		BEFORE MPC	AFTER MPC	ALL VEHICLES	REJECTED VEHICLES *	
CONTROLLED						
100	35.7	45.9	29.5	26.46	-----	.011
10	15.2	113.0	42.7	-----	8.59	.0087
25	25.1	86.7	40.1	-----	12.94	.0079
50	34.5	67.1	35.5	-----	20.63	.0092
UNCONTROLLED						
100	34.9	83.8	54.6	28.66	-----	.0062
10	10.4	176.8	90.3	-----	9.38	.0068
25	18.7	141.0	78.8	-----	13.74	.0055
50	28.6	114.6	66.9	-----	20.76	.0054

* Assumes a $5 fee for an inspection test on all vehicles.
Rejected vehicles are retested once.

This is shown graphically from plots of HC levels versus the number of vehicles at these HC levels in Figures 2. and 3. Figure 2. shows the HC distribution for uncontrolled vehicles before and after MPC tune-ups. Partial misfires are shown by the peak on the "Before MPC Tune-Ups" curve at 18 grams/mile. Complete misfires are shown by a second peak on this curve at 39 grams/mile. A comparison between the before and after MPC tune-up curves shows that the second peak was eliminated and the first peak substantially reduced by the repair.

Figure 3. shows the distribution of HC emissions for the controlled vehicles. In this group of vehicles, there was one that had a complete misfire giving 37 grams/mile. There was no distinct peak at about 18 grams/mile but there was a number of high emitters in this range that were eliminated by MPC tune-ups.

The costs assigned to the rejected vehicles in Tables 16 and 17 assume that all vehicles are tested at a cost of $5. The rejected vehicles are retested after repair. The cost tabulated is the average cost per vehicle. In other words, the cost to test and repair all vehicles is divided by the total vehicle fleet. These cost figures are used to calculate a cost-effectiveness quotient. The quotient is the average cost per vehicle divided by the reduction in total grams/mile for all vehicles.

Table 17 shows that the rejection and repair of the highest 10% emitters of CO are not as effective or cost effective as rejecting and repairing 25% to 50% of the vehicles. This is true because the greatest reductions in CO from both controlled and uncontrolled vehicles were from the moderately high emitters and not the highest emitters as was the case for HC. This is shown in distribution graphs in Figures 4. and 5.

An over-all view of the effectiveness, cost, and cost effectiveness of rejecting and repairing various percentages of the vehicles can be attained by studying the graphs in Figure 6. The top graph is for HC emissions and the lower one is for CO emissions. The solid lines are for the controlled vehicles and the dashed lines for the uncontrolled vehicles.

It is interesting to compare the level of cost-effectiveness curves for controlled and uncontrolled vehicles. The control of HC in uncontrolled vehicles is much more cost effective than in controlled vehicles. This is because much greater reductions are achieved at roughly the same costs. The slope of the cost-effectiveness curve for the uncontrolled vehicles is much less than for controlled vehicles. Tuning all of the uncontrolled vehicles is about twice as cost effective as tuning the upper 10% of the controlled vehicles--even though the repair of these 10% is the most cost effective for controlled vehicles. This does not indicate that the controlled vehicles are not cost effective but does emphasize the very high cost-effectiveness of tuning uncontrolled vehicles.

FIGURE 2

HC EMISSION DISTRIBUTION OF UNCONTROLLED VEHICLES

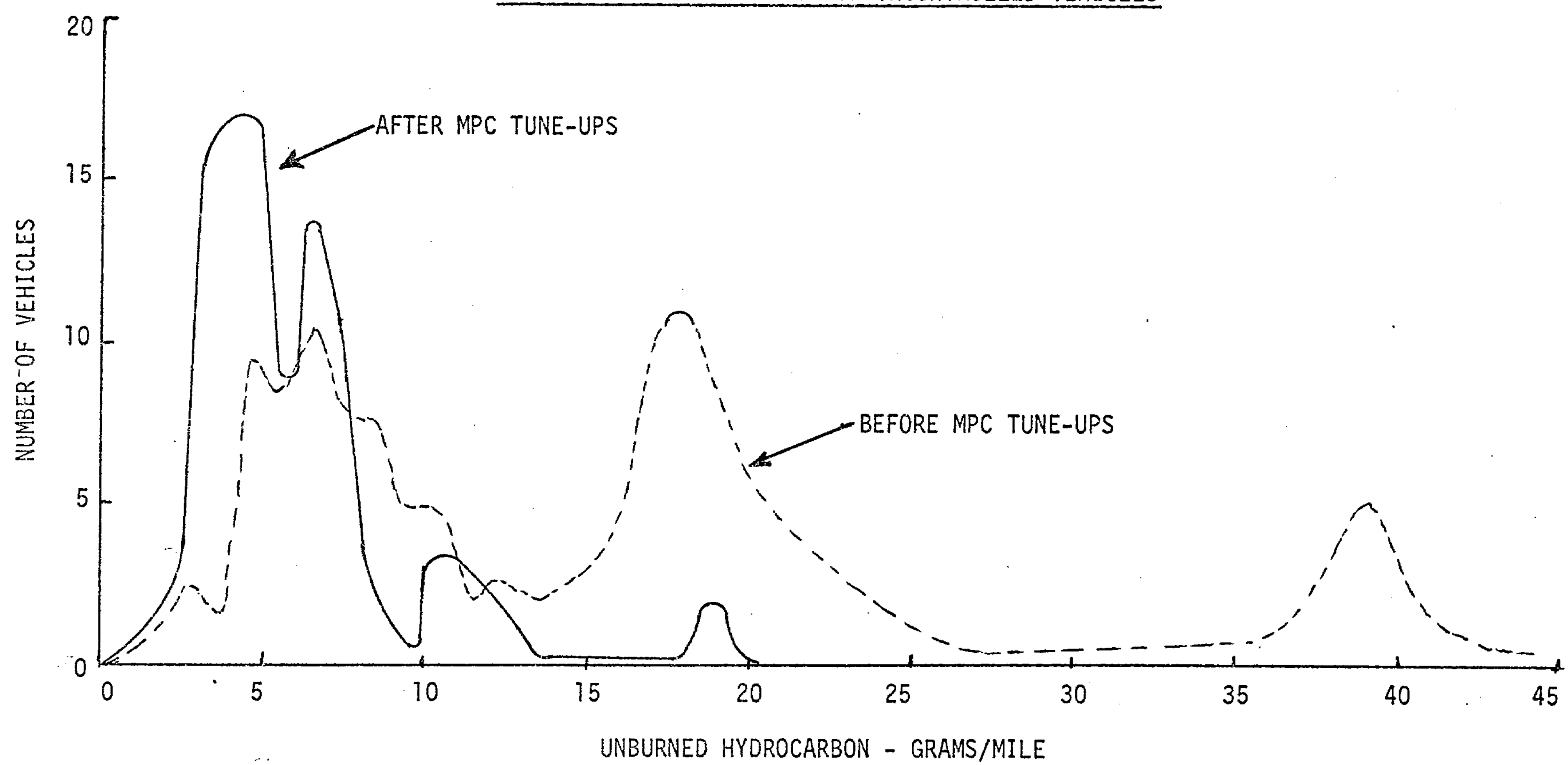


FIGURE 3

HC EMISSION DISTRIBUTION OF CONTROLLED VEHICLES

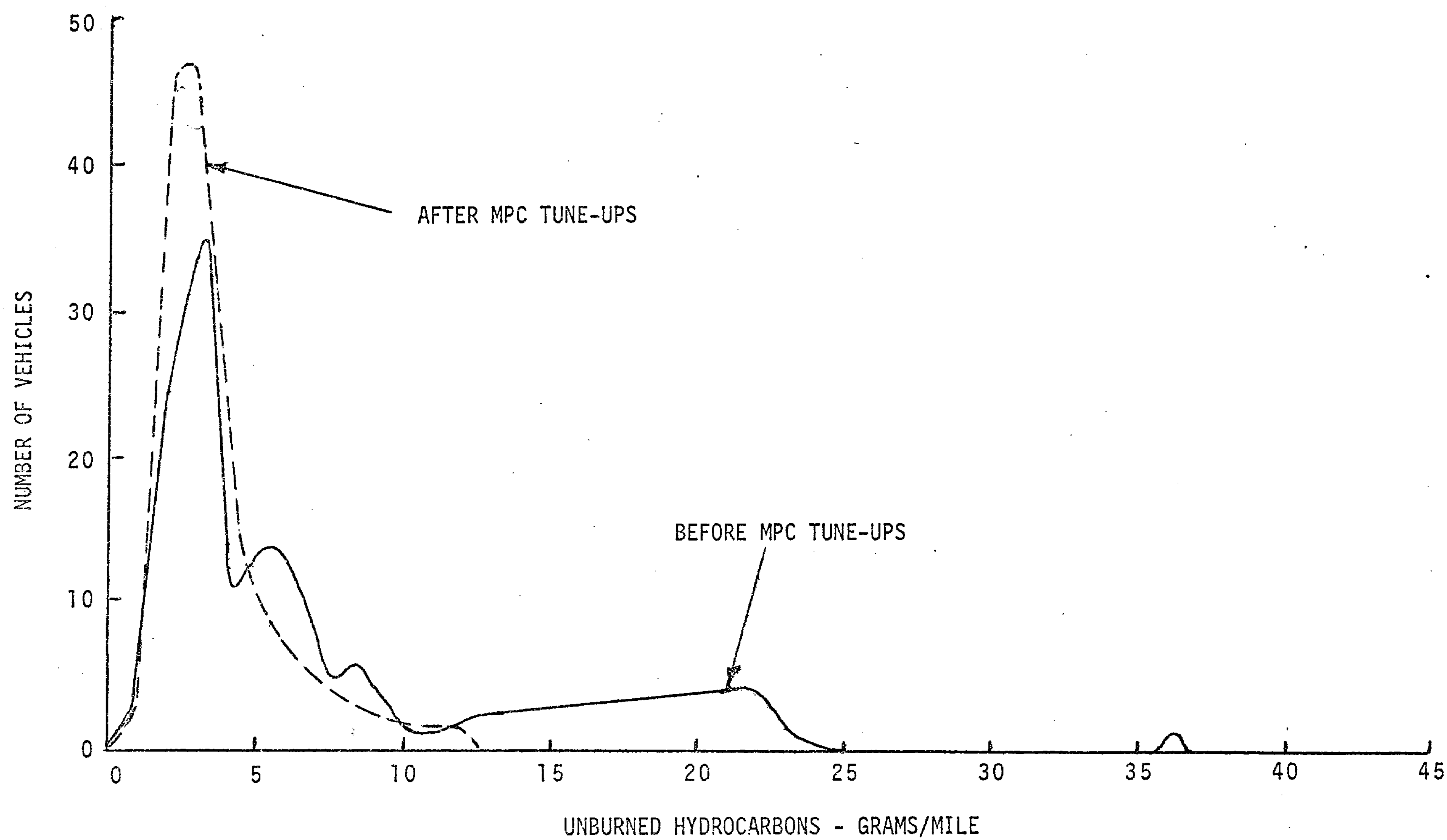


FIGURE 4

CO EMISSION DISTRIBUTION OF UNCONTROLLED VEHICLES

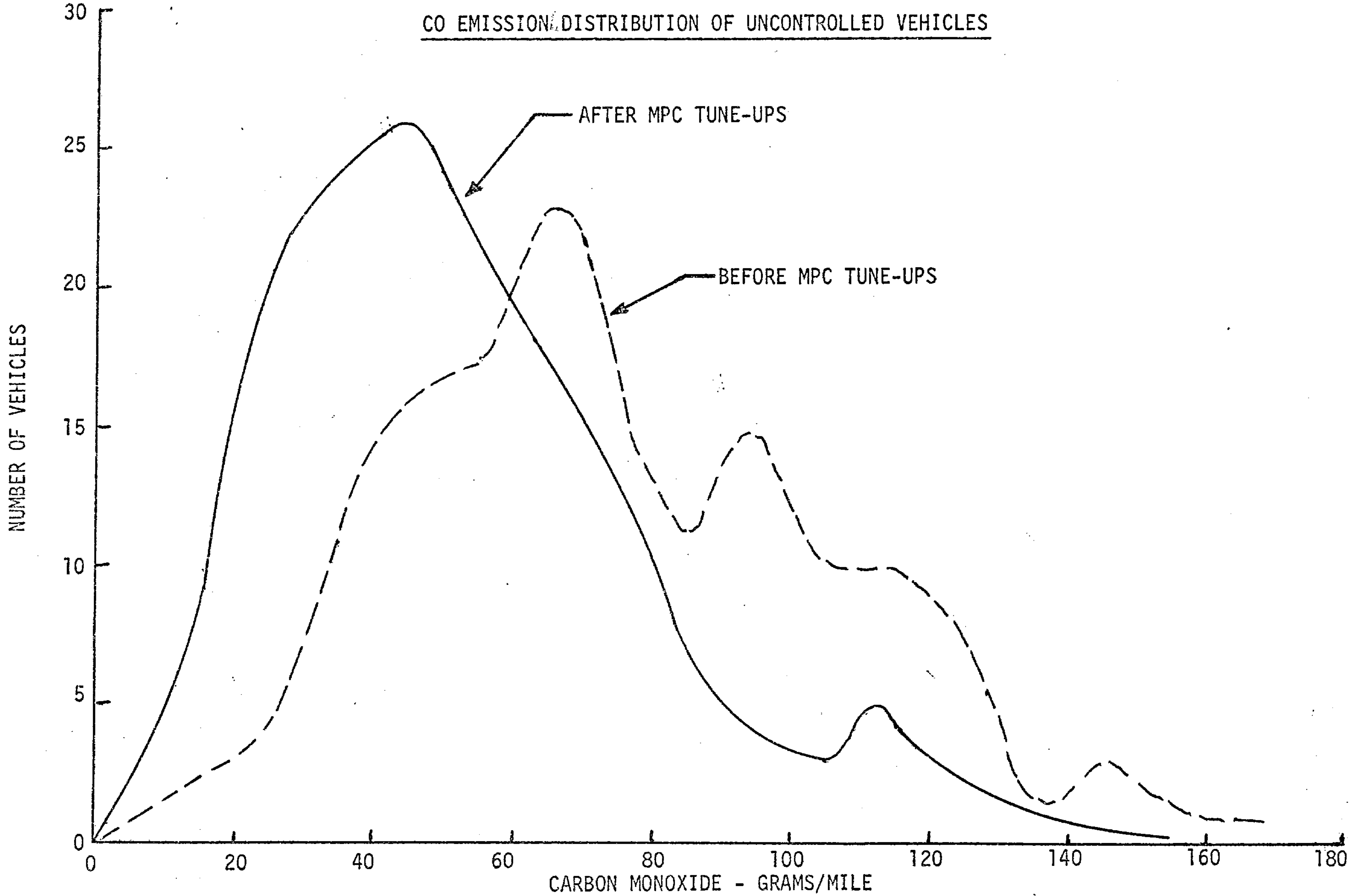


FIGURE 5

CO EMISSION DISTRIBUTION OF CONTROLLED VEHICLES

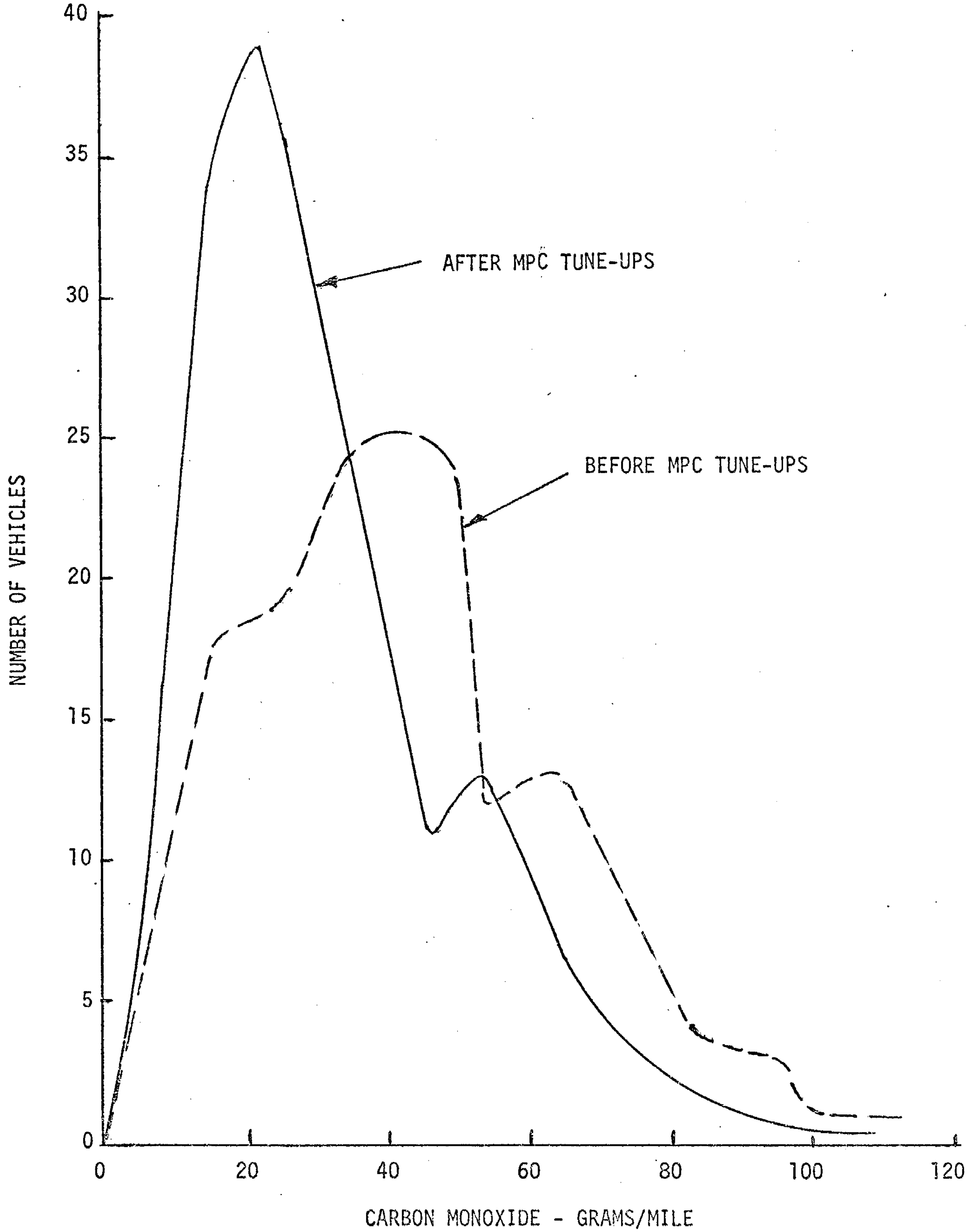
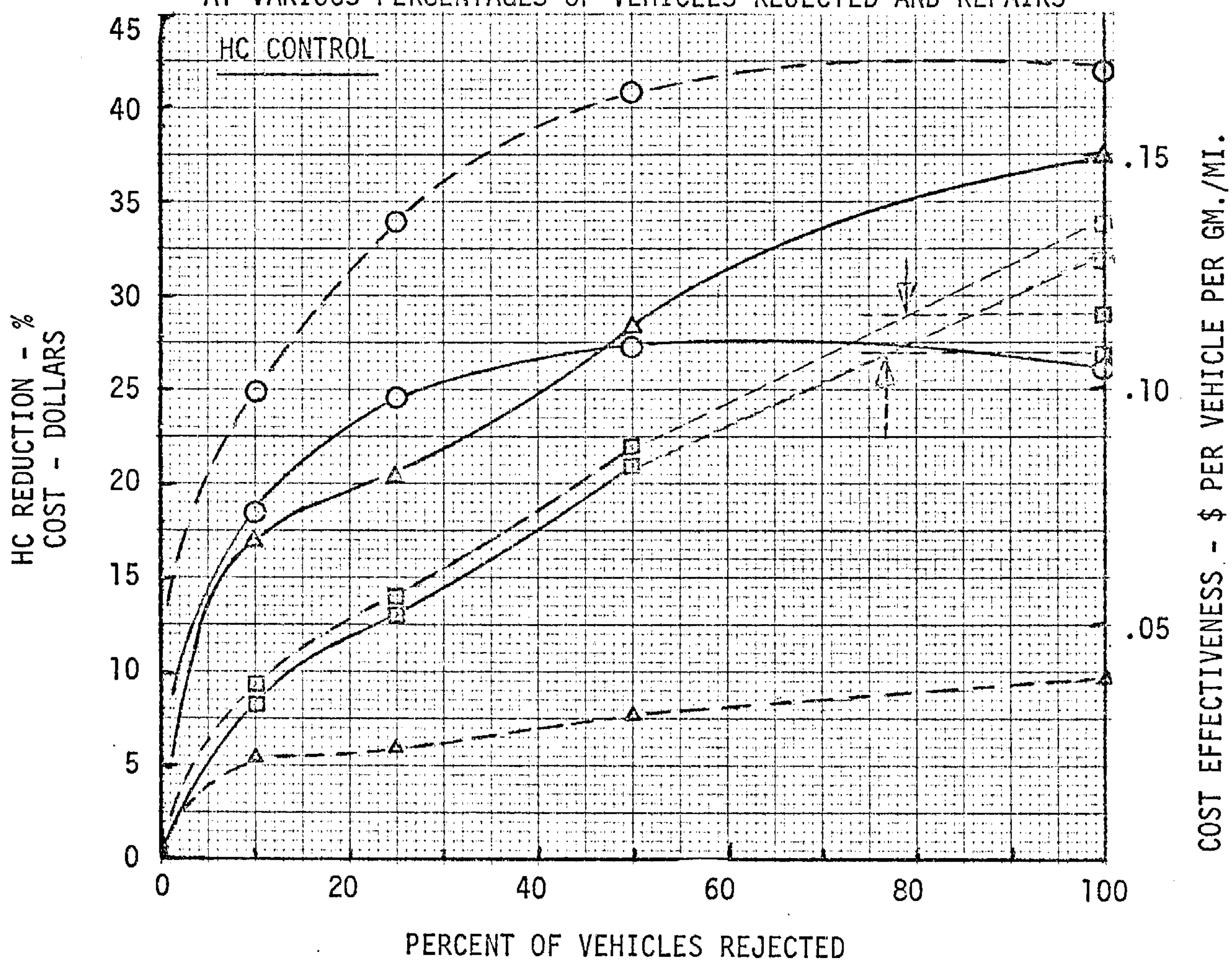


FIGURE 6

EMISSION REDUCTIONS, COSTS AND COST-EFFECTIVENESS AT VARIOUS PERCENTAGES OF VEHICLES REJECTED AND REPAIRS



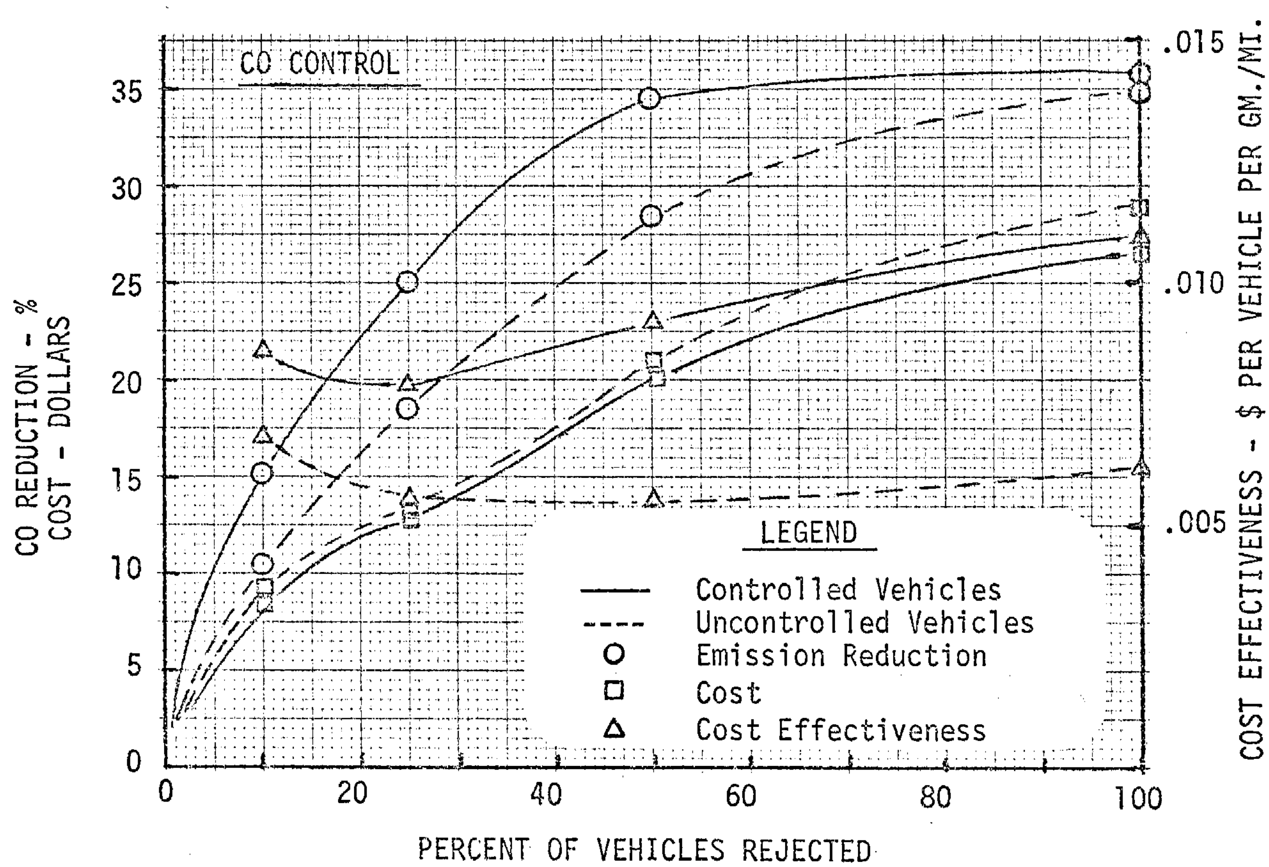


Figure 6. shows that the cost effectiveness of tuning uncontrolled and controlled vehicles for CO control is more nearly the same, particularly when a small percentage of the vehicles are repaired. MPC tune-ups are still more cost effective on uncontrolled vehicles but the difference is less than 2 to 1. In contrast to HC control, the cost effectiveness for CO control of both groups of vehicles is poorer when 10% of the vehicles are repaired.

When approximately 75% to 80% of the vehicles are tested and repaired, the cost equals that to tune all of the vehicles. This is shown by extrapolating the HC control cost curves in Figure 6. to points $10 higher than the costs for all of the vehicles ($5 to test and $5 to retest). The intersections of these extrapolations and the tune-up costs for all vehicles are at 75% to 80%.

In Figure 7., the HC emissions for uncontrolled vehicles before and after MPC tune-ups are plotted against the accumulative percentage of these vehicles. The area between these curves is proportional to the amount of HC emissions controlled by tuning all vehicles. If 25% of the vehicles were rejected and repaired, then it would appear that the area between the curves in Region C would be eliminated. This assumes that these vehicles stay within Region C after tune-up. In the data analysis described previously, the rejection and repair of 25% of the vehicles resulted in an 80% reduction in HC. A comparison of the areas in Figure 7. shows only about a 60% reduction. Therefore, some of the higher emitting vehicles in Region C must have moved into one of the lower emission regions. Without this knowledge, it would appear that tuning only 25% of the vehicles would leave the HC emissions in Regions A and B.

One problem with rejecting vehicles above a certain emission level is that some vehicles rejected may already be at their minimum emission level. This can be illustrated in Figure 7. by observing that horizontal lines labeled 25% and 50% rejection intersect both the before and after MPC tune-up curves.

The test data was analyzed to determine if a simple no load test (using garage-type HC and CO meters) could be helpful in detecting the low emission vehicles that perhaps should not be tuned. Several plots of no-load emissions versus 7-mode emissions were made to determine if there was any correlation. The following emission measurements taken by Class A mechanics were plotted against 7-mode HC emissions.

(1) .3 HC @ idle + .7 HC @ 2500 RPM

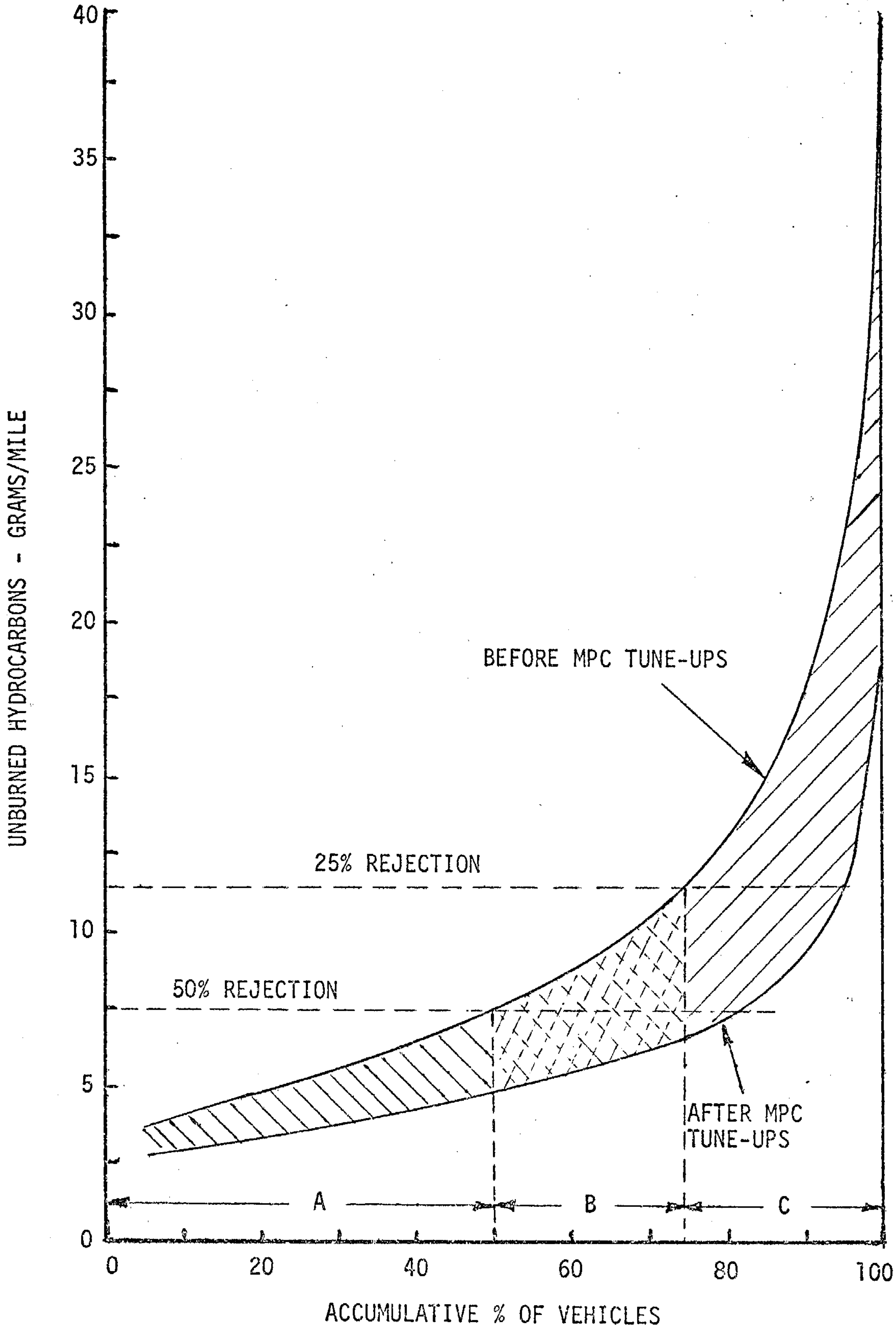
(2) HC @ 2500 RPM

(3) HC @ idle

(4) CO @ idle

FIGURE 7

MPC TUNE-UPS ON REJECTED VEHICLES ONLY



The following emission measurements taken by Class A mechanics were plotted against 7-mode CO emissions:

(1) CO @ idle

(2) CO @ 2500 RPM

None of the above plots showed any useful correlation.

It has been shown[2] that the idle measurements taken during 7-mode cycle hot emission tests are useful in isolating vehicles with high emissions. The correlation between idle measurements made during 7-mode emission tests and those made by the ten Class A stations is shown in Figure 8. The wide scatter of points shows that this inspection method may be less effective when measurements are made by several operators and with several instruments. Figure 9 is a comparison involving one mechanic and one instrument. Possible reasons for this poor correlation could be:

(1) variations in conditions such as engine operating temperatures,

(2) mechanical variations in the engine such as carburetor float level,

(3) improper instrument readings, and

(4) defective or improperly calibrated meters.

Another important factor to consider in determining if every vehicle should be periodically tuned to MPC or if the lower emitters should be excluded is the amount of degradation in emission control in service. It is possible that the preventative maintenance and other work performed in the MPC tune-ups on vehicles that increased in HC could have prevented these vehicles from increasing substantially. This is discussed further in the next section where the test results after six months are presented.

d. After Six Months of Service

A total of 267 vehicles were returned for six month emission tests. Of the 33 vehicles not returned, 11 were junked, 15 were sold or moved out of the area and the other 7 were uncooperative or could not be contacted. The results of tests before and after MPC tune-ups on these vehicles show that they were reasonably representative of the total fleet. Therefore, their loss should not bias the six month results. The initial test results on these 33 vehicles are compared with the other 267 vehicles in Table 18.

A comparison of the average emissions before and after MPC tune-ups for the original 300 vehicle fleet and the 267 vehicle fleet is shown in Table 19. The two fleets show very good agreement.

FIGURE 8

IDLE CO MEASURED BY VARIOUS CLASS A MECHANICS
VERSUS IDLE CO MEASURED DURING 7-MODE TEST

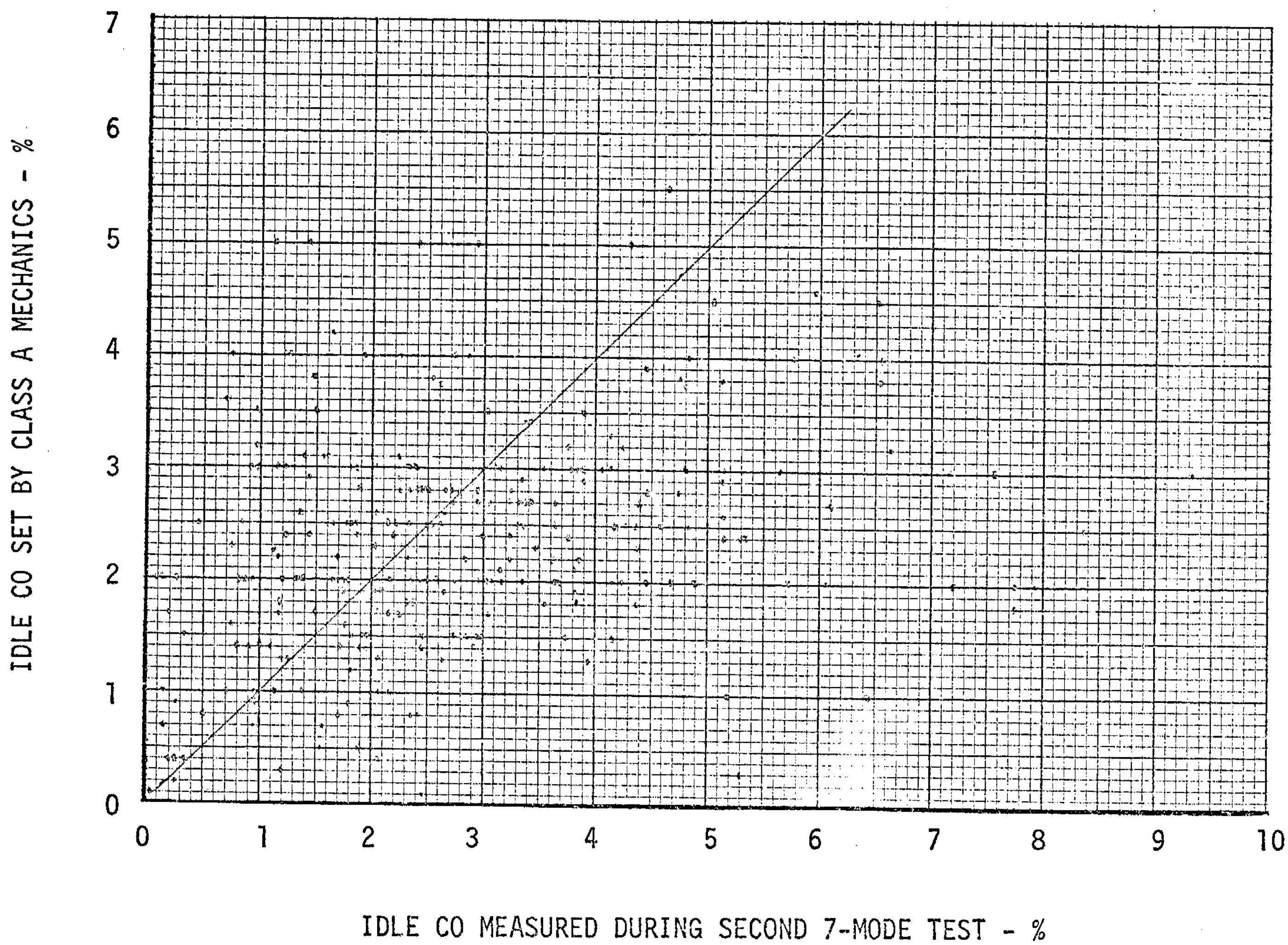


FIGURE 9

IDLE CO MEASURED BY CARCO CLASS A MECHANIC
VERSUS IDLE CO MEASURED DURING 7-MODE TEST

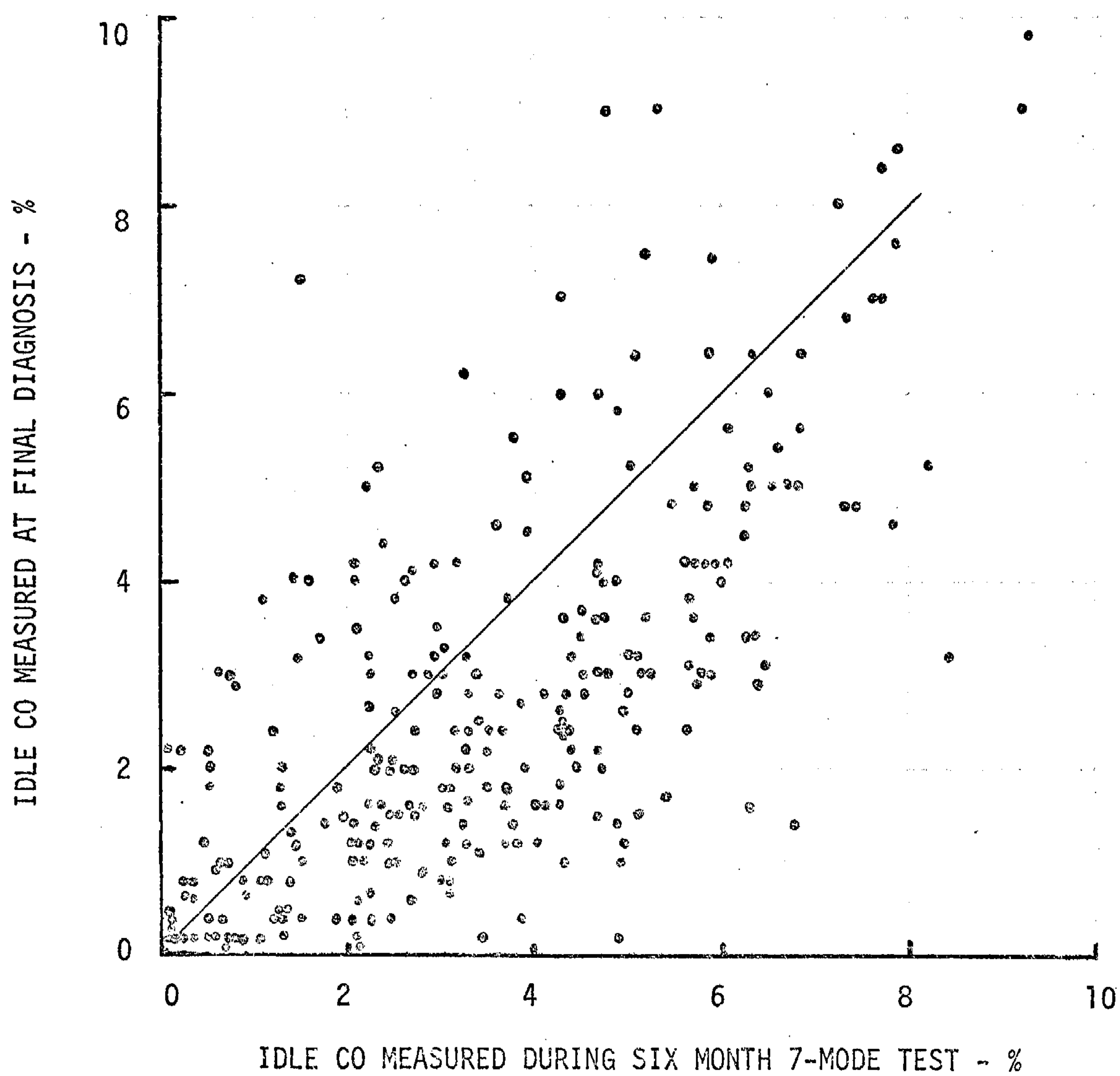


TABLE 18

INITIAL TEST RESULTS FOR VEHICLES NOT RETURNED FOR SIX MONTH EMISSION TEST

PARAMETER	BEFORE MPC TUNE-UP		AFTER MPC TUNE-UP		% CHANGE	
	33 Vehicles Not Returned	267 Vehicles Returned	33 Vehicles Not Returned	267 Vehicles Returned	33 Vehicles Not Returned	267 Vehicles Returned
HC - Gms./Mi.	8.89	7.83	4.84	4.96	-45.5	-36.7
CO - Gms./Mi.	70.3	65.4	46.4	42.4	-34.0	-35.2
NOX - Gms./Mi.	3.49	3.72	3.66	3.93	+ 4.9	+ 5.6
Fuel - Gms./Test	494	482	477	458	- 3.4	- 5.0
Cost	$27.77	$27.40	----	----	----	----

(1) <u>7-Mode Test Results</u>

The results of 7-mode tests performed after six months of service are very promising. These results are shown in Table 20. The 267 vehicles tested are divided into the following four groups:

Group 1: No repairs or adjustments performed during the six month period. This group represents 62% of the vehicles.

Group 2: The owners of vehicles in this group complained that the operation of their vehicles was not acceptable and they would not "live with it" for six months. The vehicles were returned to the same Class A mechanics who performed the tune-ups whenever possible. Twelve percent (12%) of the vehicles were in this group.

Group 3: The owners of vehicles in this group performed work on the engines of their vehicles which may have affected the emission levels. Twenty-two percent (22%) of the vehicles were in this group.

Group 4: This group is a combination of groups 2 and 3. They represent 4% of the vehicles.

TABLE 19

COMPARISON BETWEEN INITIAL 300 VEHICLE FLEET AND
267 VEHICLE FLEET RETURNED FOR 6 MONTH TESTING

TYPE OF VEHICLES	NO. OF VEHICLES	HC - GRAMS/MILE		CO - GRAMS/MILE		NOX - GRAMS/MILE		COST $/VEHICLE
		BEFORE MPC	AFTER MPC	BEFORE MPC	AFTER MPC	BEFORE MPC	AFTER MPC	
CONTROLLED	141	4.82	3.55	45.9	29.5	4.28	4.47	26.46
	127	4.62	3.55	45.6	29.1	4.30	4.52	26.75
UNCONTROLLED	158	10.8	6.22	83.8	54.6	3.21	3.38	28.66
	140	10.7	6.23	83.4	54.3	3.19	3.41	28.05

TABLE 20

CHANGES IN EMISSIONS [1] AND FUEL CONSUMPTION [2] DURING SIX MONTHS

TYPE OF SERVICE DURING 6 MONTHS	PARAMETERS	NO. OF CARS	BEFORE MPC (AVG.)	AFTER MPC (AVG.)	AFTER 6 MOS. (AVG.)	% CHANGE AFTER SIX MONTHS		AVERAGE COST OF TUNE-UPS
						FROM BEFORE MPC	FROM AFTER MPC	
GROUP 1	HC	165	7.09	4.78	5.46	-23.0	+14.2	$27.13
No Service	CO	165	62.4	42.7	43.5	-30.3	+1.9	
	NOX	165	3.87	3.98	4.02	+3.88	+1.0	
	FUEL	140	483	463	465	- 3.7	+.43	
GROUP 2	HC	33	9.52	5.41	5.92	-37.8	+9.4	$31.54
Class A Mechanic Repair or Adjust.	CO	33	82.7	44.5	51.6	-30.4	+29.4	
	NOX	33	3.16	3.96	3.76	+19.0	-5.0	
	FUEL	27	525	483	497	- 5.3	+2.9	
GROUP 3	HC	59	8.14	5.32	5.49	-32.6	+3.2	$24.61
Owner Repair or Adjustment	CO	59	66.7	40.8	46.7	-30.0	+14.5	
	NOX	59	3.64	3.85	3.54	- 2.7	-8.0	
	FUEL	48	456	431	446	-2.19	+3.5	
GROUP 4	HC	10	12.54	4.24	5.26	-58.1	+24.1	$34.57
Class A Mechanic or Owner Repair or Adjustment	CO	10	51.7	39.6	39.1	-24.4	-1.3	
	NOX	10	3.46	3.61	3.92	+13.3	+8.6	
	FUEL	6	469	457	429	- 8.5	-6.1	
TOTAL FLEET	HC	267	7.83	4.96	5.52	-29.5	+11.3	$27.40
	CO	267	65.4	42.4	45.8	-30.0	+8.0	
	NOX	267	3.72	3.93	3.88	+ 4.3	-1.3	
	FUEL	221	482	458	464	- 3.7	+1.3	

1) Grams per mile
2) Grams per test

The six month changes in emissions and fuel consumption were calculated for each group. The percent change of these parameters relative to the before and after tune-up values are tabulated in Table 20. The increases in emissions and fuel consumption of the 165 vehicles in Group 1 during the six months were small. This is very encouraging in contrast to the results obtained in a study by Northrop Corporation (3). In this study, 50% of the higher emitting fleet vehicles were repaired. After six months, they were retested and the fleet emissions were at approximately the same level as before testing and repair. This indicates that the preventative maintenance steps in the MPC tune-up procedure are effective. The HC reductions for the Group 1 vehicles are lower than the other groups. One explanation is that these vehicles were in better condition and were, therefore, tuned without difficulty or complaints. The lower HC levels support this explanation.

The six month tests on the total fleet of vehicles show about the same results. The slight improvement in NO_X is probably due to the increase in CO. Carburetors usually become richer in use and the result decreases NO_X. The increased fuel consumption corresponds to the increased CO.

The Group 2, 3, and 4 vehicles had higher emissions prior to the MPC tune-ups than the Group 1 vehicles. The emission reductions after MPC tune-ups were also higher. Greater changes in engine adjustments and repairs during the MPC tune-ups probably provided the higher emission reductions. They probably also resulted in owner complaints and extra engine work. The large decreases in CO after MPC tune-ups for Groups 2 and 3 and the subsequent increase over six months indicate that carburetor repair was involved. The cost figures for tune-ups shown in Table 20 support this thought for Group 2 but not for Group 3.

It is important to note that if the Class A stations were upgraded with HC-CO meters and the mechanics trained to perform low emission tune-ups, that the emissions levels could stay down even if about one-third of the vehicles received work after the tune-up. Under these conditions, the owner would usually return his vehicle to an upgraded station for this work. Most of the time, they would return it to the station performing the original tune-up. Changes in the MPC tune-up procedure discussed in Section III,B,7 could reduce the number of dissatisfied owners.

The vehicle owners were requested not to do any work on their engines unless they contacted CARCO. If a complaint occurred, the CARCO mechanic established if the problem was involved with the MPC tune-up. If the tune-up was involved but did not create a severe or unsafe situation, the owner was asked to "live with it". If the problem was serious or unacceptable to the owner, the vehicle was sent to the Class A mechanic who performed the tune-up. A more detailed explanation of the ground rules used for handling owner complaints is given in Table D-3 in Appendix D.

At the time of the six month interview, the owner was asked if any work was done to the engine of his vehicle. This interview information, work documented at time of complaints, and data gained from the through diagnoses at six months were used to place vehicles in the four groups discussed above.

In Table 21, the vehicles are divided into two general classifications -- "No Service" and "With Service"--during the six months. It is interesting to note that before the tune-up, HC emissions of vehicles "with service" were about 25% higher than the "no service" vehicles. The after tune-up emissions for both classifications were nearly the same. The tune-up costs for both classifications were also nearly the same.

Six month emission results for controlled and uncontrolled vehicles are given separately in Table 22. The HC percent reduction after six months is considerably more on the uncontrolled vehicles than the controlled (36.5 versus 11.2). On the basis of mass emissions removed from the air, MPC tune-ups on uncontrolled vehicles were removing over four times as much HC emissions as controlled vehicles. Since the cost of tune-ups for both classes of vehicles is roughly the same, the cost effectiveness of tune-ups on older vehicles is four times greater.

Graphs showing the distribution of HC and CO emissions for the total fleet are shown in Figures 10 and 11 respectively. These graphs show that emission levels vary greatly over the vehicle population. The top curves represent the emissions of the test fleet before the MPC tune-ups. The lower curves represent the emissions of the fleet after MPC tune-ups. The area between these curves is proportional to the quantity of emissions eliminated by the tune-ups. The curves labeled "After Six Months" show the emissions of the test fleet after six months of service. The area between the two lower curves represents the degradation of MPC tune-ups in six months.

A display of the test data in this manner is useful in showing how changes such as tune-ups affect the emissions of the test fleet as a whole. It cannot be assumed that a vehicle at any point on the "Before MPC Tune-up" curve was lowered to that same point on the lower curve labeled "After MPC Tune-up". A vehicle's position on the accumulative % of vehicles scale may change also. These graphs show the distribution of emission levels for a population of vehicles under a given set of conditions.

In Figure 10, it is shown that the greatest HC reductions with MPC tune-ups are attained with the higher emitting vehicles. The amount of degradation during the six months of service is small relative to the initial reductions. The reductions of CO shown in Figure 11 appear to be the greatest with vehicles at the 60 to 80 accumulative % area. It is interesting to note that the highest CO emitters were not substantially reduced. The degradation of CO control during the six month period was small.

TABLE 21

EMISSION AND FUEL CONSUMPTION CHANGES OF VEHICLES WITH AND WITHOUT SERVICE DURING SIX MONTHS

SERVICE DURING 6 MONTHS	PARAMETERS	NO. OF CARS	BEFORE MPC (AVG.)	AFTER MPC (AVG.)	AFTER 6 MOS. (AVG.)	% CHANGE AFTER SIX MONTHS		AVERAGE COST
						FROM BEFORE MPC	FROM AFTER MPC	
No Service Reported or Detected at Six Month Diagnosis	HC - Gm/Mi	165	7.09	4.78	5.46	-23.0	+14.2	$27.13
	CO - Gm/Mi	165	62.4	42.7	43.5	-30.3	+1.9	
	NOX - Gm/Mi	165	3.87	3.98	4.02	+ 3.9	+1.0	
	FUEL- Gm/Test	140	483	463	465	- 3.7	+ .4	
<u>WITH SERVICE</u> By Owner or Class A Mechanic Resulting from Owner Complaint	HC - Gm/Mi	102	9.02	5.24	5.61	-37.8	+7.1	$27.83
	CO - Gm/Mi	102	70.4	41.9	49.5	-29.7	+18.1	
	NOX - Gm/Mi	102	3.47	3.86	3.65	+ 5.2	-5.4	
	FUEL- Gm/Mi	81	480	450	462	- 3.7	+2.7	

TABLE 22

EMISSION AND FUEL CONSUMPTION CHANGES FOR UNCONTROLLED AND CONTROLLED VEHICLES DURING SIX MONTHS

PARAMETERS	NO. OF CARS	BEFORE MPC (AVG.)	AFTER MPC (AVG.)	AFTER 6 MOS. (AVG.)	CHANGE AFTER SIX MOS. - %	
					FROM BEFORE MPC	FROM AFTER MPC
CONTROLLED						
HC - Gm/Mi	127	4.62	3.55	4.10	-11.2	+15.5
CO - Gm/Mi	127	45.6	29.1	33.2	-27.2	+14.1
NOX - Gm/Mi	127	4.30	4.52	4.30	0	-4.87
FUEL - Gm/Test	111	469	456	457	-2.56	+ .22
AVERAGE COST:	127	$26.75				
UNCONTROLLED						
HC - Gm/Mi	140	10.7	6.23	6.80	-36.5	+9.15
CO - Gm/Mi	140	83.4	54.3	57.1	-31.5	+5.16
NOX - Gm/Mi	140	3.19	3.41	3.50	+9.72	+2.64
FUEL - Gm/Test	110	495	456	470	-5.05	+3.07
AVERAGE COST:	140	$28.05				

FIGURE 10

DISTRIBUTION OF HC EMISSIONS
FOR TOTAL TEST FLEET

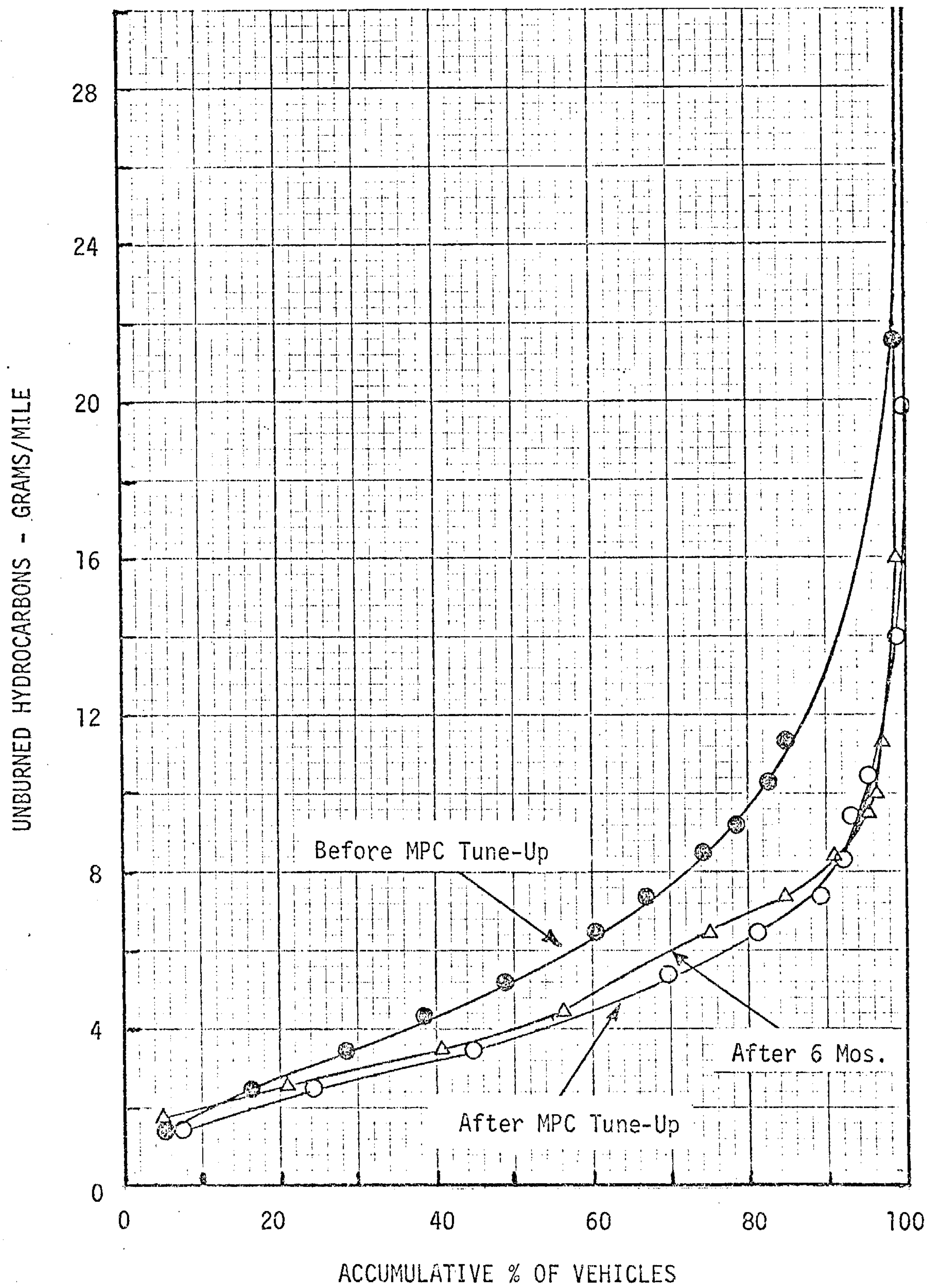
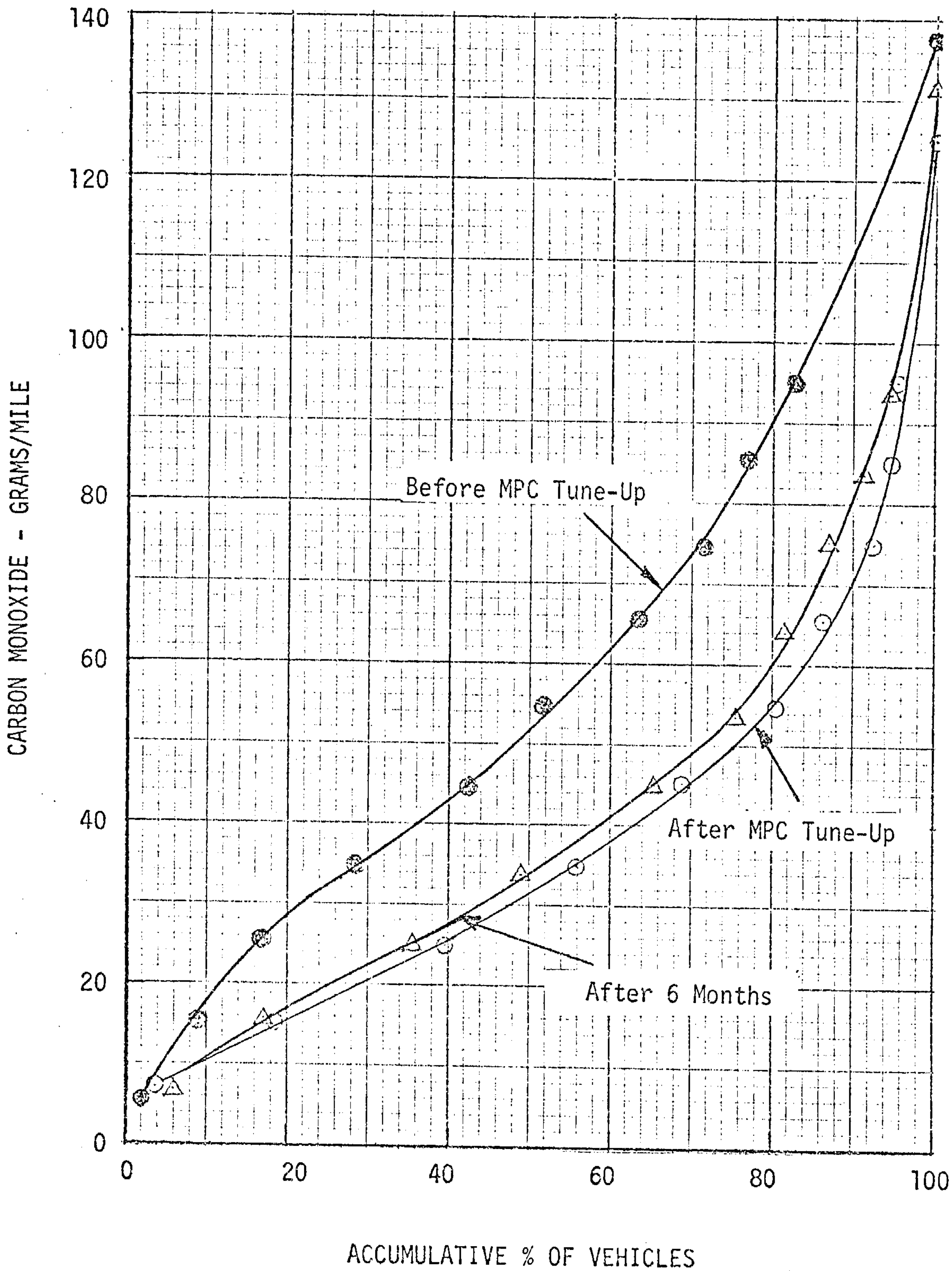


FIGURE 11

DISTRIBUTION OF CO EMISSIONS
FOR TOTAL TEST FLEET



(2) Degradation of MPC Tune-Up Emission Control

Figures 12 and 13 show distribution curves for the emissions of the uncontrolled vehicles in the test fleet. The substantial HC reductions with MPC tune-ups previously reported on this group of vehicles is shown by the large area between the two curves. The amount of emission degradation is shown by the area between the "after MPC tune-up" and "after 6 months" curves. Figure 13 shows how the distribution of HC changed after six months of service. After the MPC tune-ups, there was a high emission peak of four vehicles averaging 18.9 grams per mile. After six months, there was a two vehicle peak averaging 23.4 grams per mile.

Distribution curves for the CO emissions of the uncontrolled vehicles shown in Figure 14 are similar to those for the total fleet. The degradation was very small even though the initial reductions were large.

The HC distribution curves for the controlled vehicles are shown in Figure 15. The shape of these curves are different than those for the uncontrolled vehicles because most of the emission levels are low except for a few high emitters. These high emitters were caused by partial or complete ignition misfires. They weigh heavily on the average emissions of the total fleet. For example, the after tune-up HC emissions were 26.3% lower than before tune-up. After tune-up, there were no vehicles over 12 grams/mile. After six months, there were two vehicles over 12 grams/mile--one at 25.2 grams/mile and the other at 49.2 grams/mile. Both of these vehicles had oil fouled spark plugs. If these two vehicles were excluded, the degradation would have been from 26.3% down to 22.5%. Including these two high emitters changed the reductions from 26.3% down to 11.2%. In other words, two vehicles with ignition misfires in a fleet of 141 vehicles reduced the benefit of tune-ups on all vehicles by a factor of 2.

This shows that misfires will become increasingly more important in lower emission vehicles where one misfiring cylinder will equal the emissions of about 25 other vehicles. Afterburners, such as catalytic converters, can help alleviate this problem provided they can endure the added heat load.

The distribution of HC emissions for the controlled vehicles is shown in Figure 16. It is shown that the emissions of the large population of vehicles shifted up slightly, but the major effect of degradation was from the two one-vehicle peaks at 25 and 49 grams/mile.

The distribution of CO emissions for the controlled vehicles is shown in Figure 17. The largest degradation of CO emission control occurred with these vehicles. Most of the degradation took place in the higher emitting 50% of the fleet. It is interesting to note the large variation in CO emission levels for these controlled vehicles.

FIGURE 12

DISTRIBUTION OF HC EMISSIONS
FOR UNCONTROLLED VEHICLES

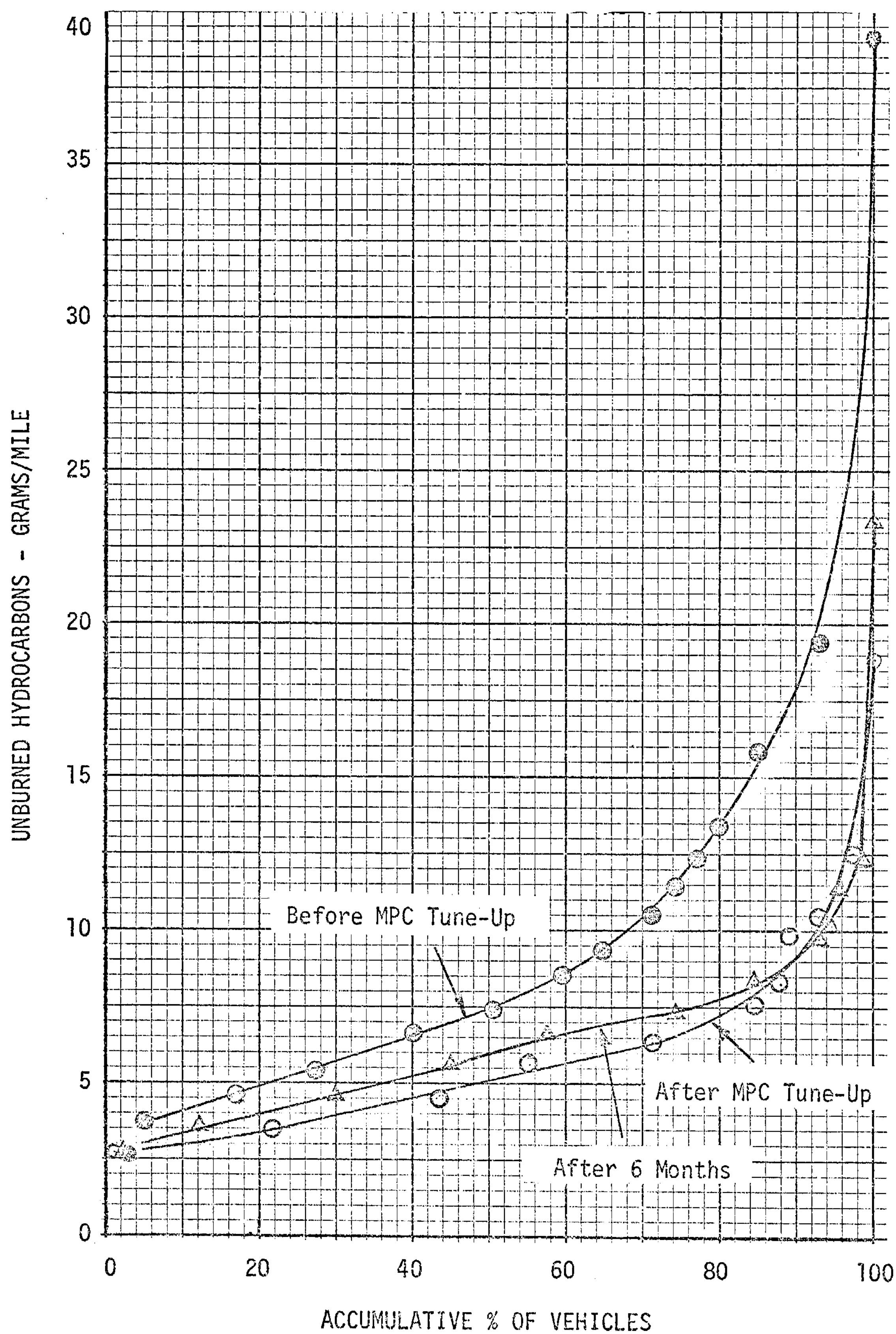


FIGURE 13

HC EMISSION DISTRIBUTION OF UNCONTROLLED VEHICLES

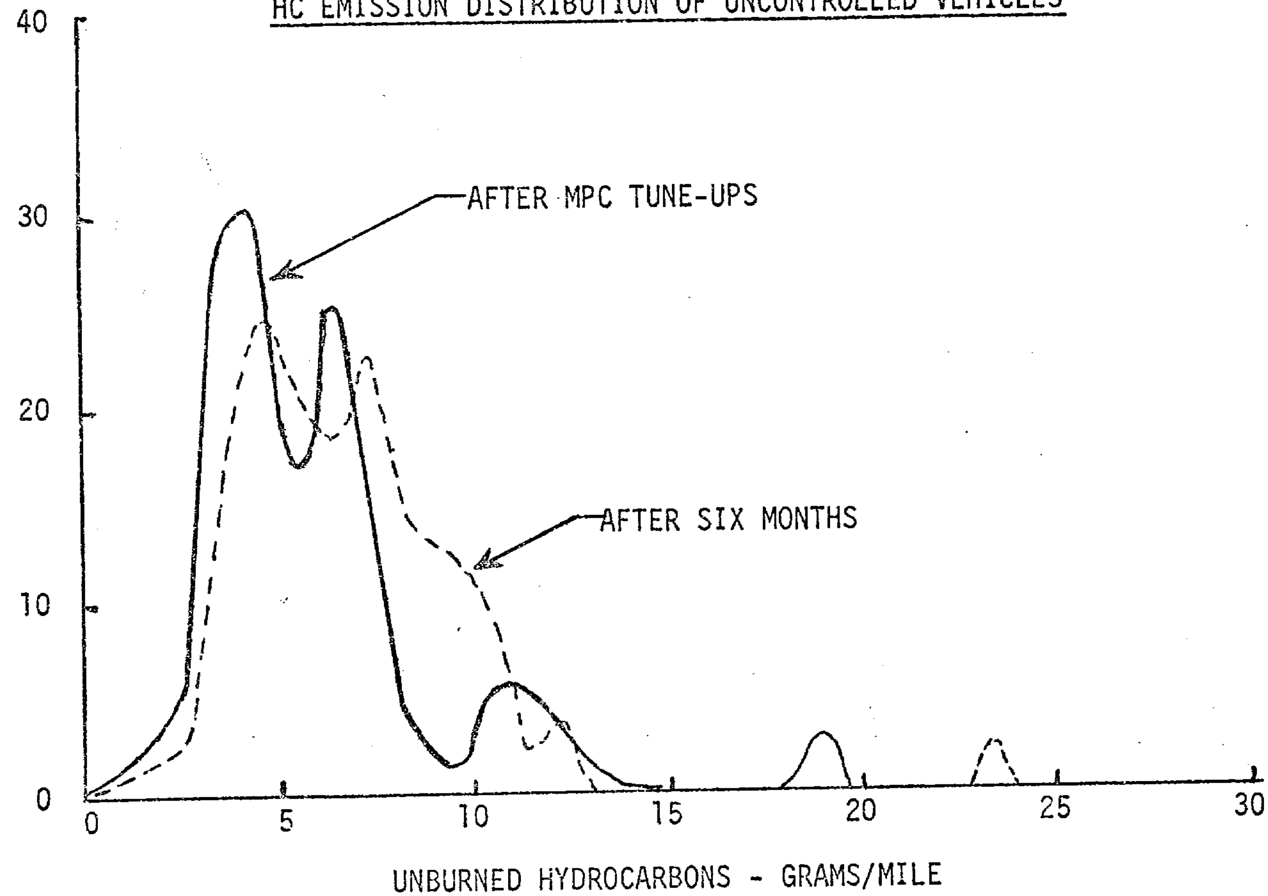


FIGURE 14

DISTRIBUTION OF CO EMISSIONS
FOR UNCONTROLLED VEHICLES

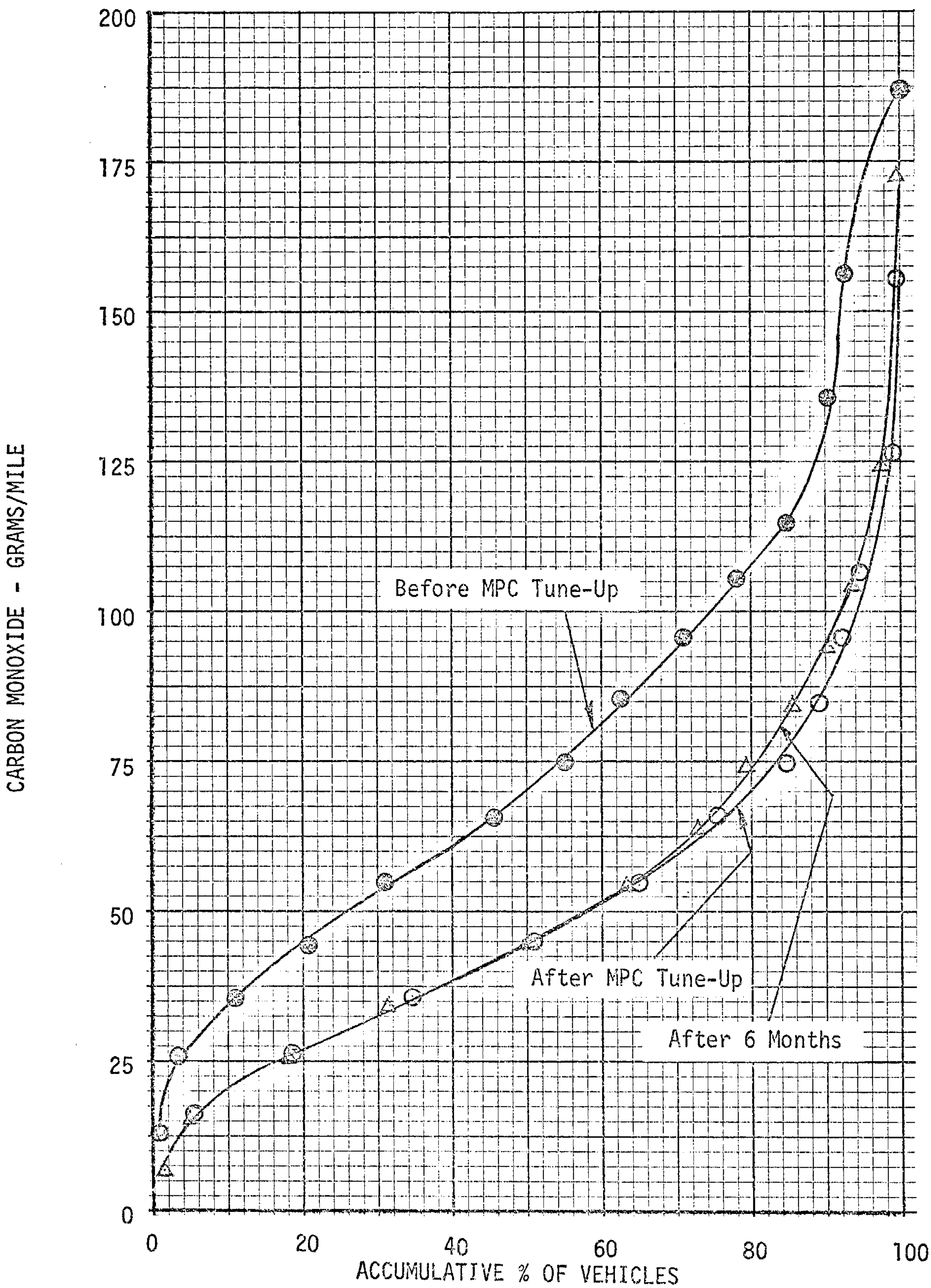


FIGURE 15

DISTRIBUTION OF HC EMISSIONS FOR CONTROLLED VEHICLES

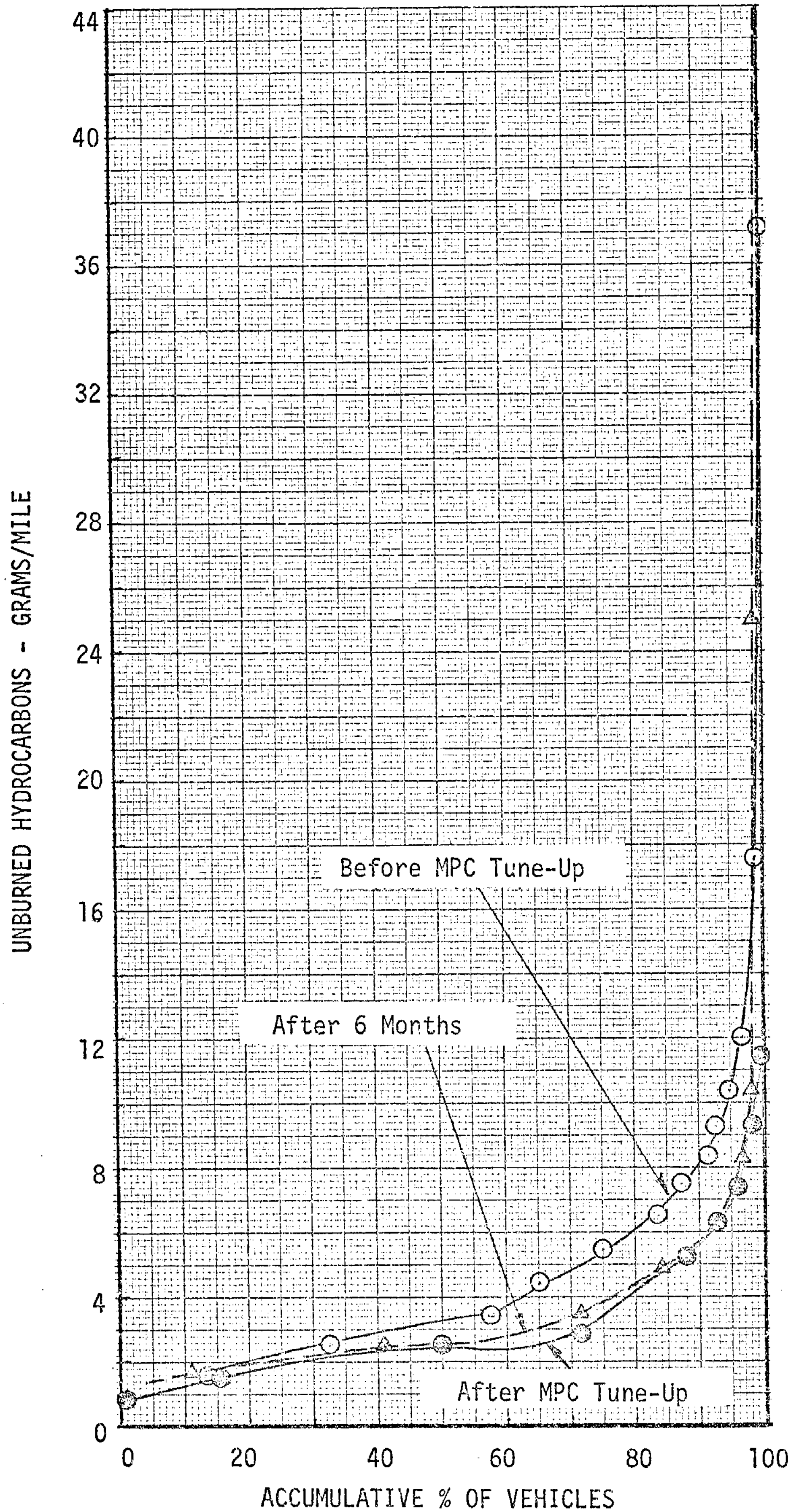


FIGURE 16

HC EMISSION DISTRIBUTION OF CONTROLLED VEHICLES

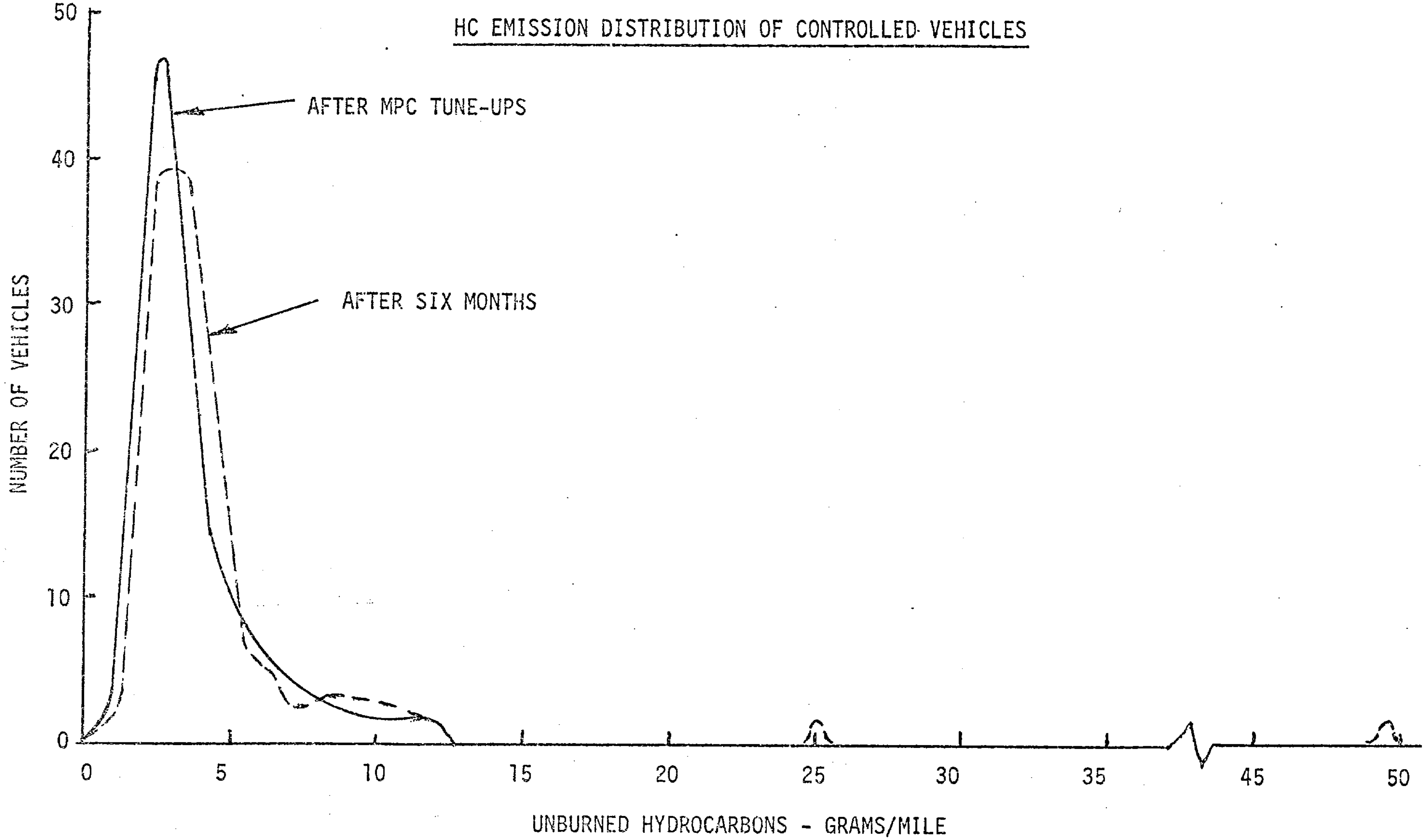
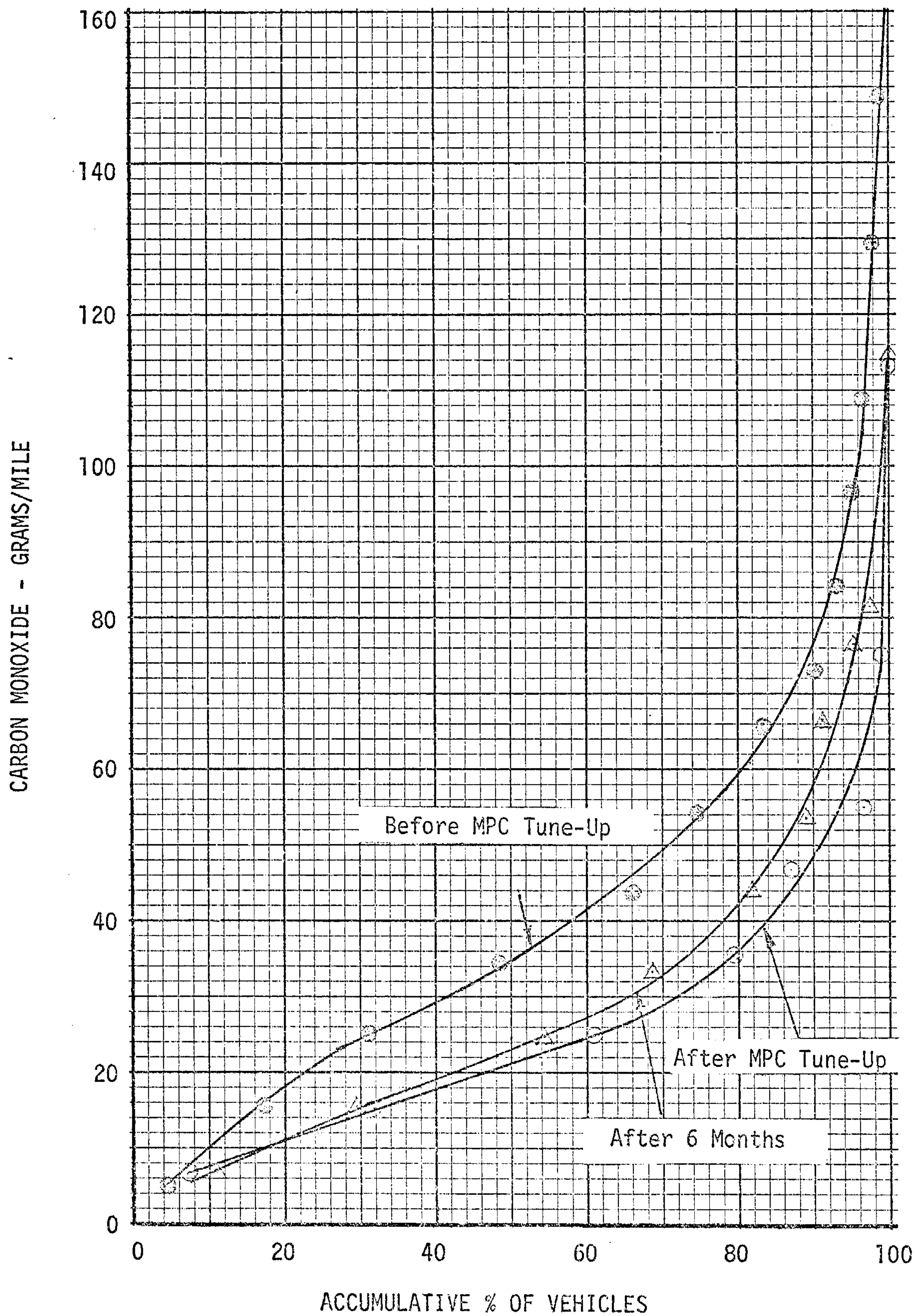


FIGURE 17

DISTRIBUTION OF CO EMISSIONS
FOR CONTROLLED VEHICLES



In order to help determine the influence of miles traveled on the degradation from six months of service, plots of HC and CO emissions were made versus mileage. Since the HC reductions obtained from MPC tune-ups were much larger with the uncontrolled vehicles, the controlled and uncontrolled vehicles were treated separately. The vehicles in each group were divided into two subgroups--those with and without service during the six months.

Plots of emissions versus mileage are shown in Figures 18, 19, 20, and 21. Each point plotted (except as noted) is the average of ten vehicles. The points at zero miles represent the average emissions for that group of vehicles after the MPC tune-ups. The average miles driven during the six month period are as follows:

Controlled Vehicles	=	5968 Miles
Uncontrolled Vehicles	=	4634 Miles
Composite	=	5283 Miles

Figure 18 shows the HC data for uncontrolled vehicles. It appears that mileage had little effect on the vehicles with no service within the 9000 mile interval. The degradation of vehicles with service was about the same except for the group of six vehicles averaging slightly over 10,000 miles. This point contained a 1963 Ford with an emission of 35 grams per mile. The vehicle was using an excessive amount of oil.

Figure 19 is the mileage versus CO emissions plot for uncontrolled vehicles. The after tune-up CO emissions for the vehicles with and without service during the six months were very close. The plot shows no significant effect of mileage on emission levels with either group. The degradation in six months was only 5%.

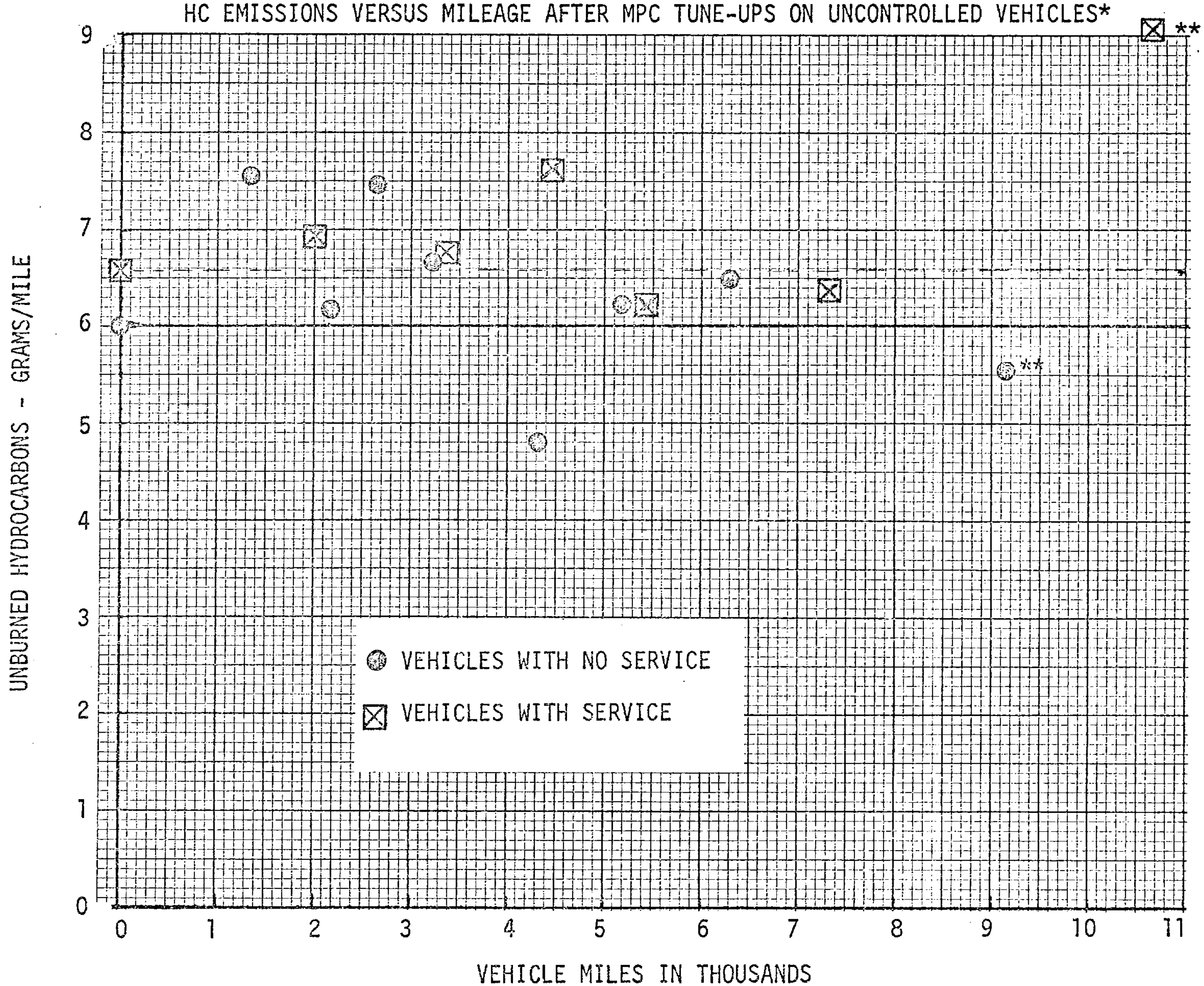
Figure 20 shows the mileage versus HC emission data for the controlled vehicles. The after tune-up emissions for the subgroups of vehicles with and without service were very close. Mileage had no significant effect on degradation. As previously stated, the largest effect of mileage on this group was the oil fouling of spark plugs in two vehicles. Points representing ten vehicle averages at about 4,000 and 8,000 miles each contain one of these high emitters.

The mileage versus CO emission data for the controlled vehicles is shown in Figure 21. There was a rather large difference in the after tune-up emissions of the vehicles with and without service during the six months. The vehicles with no service maintained the higher CO levels very well during the six months. The vehicles with service significantly increased in CO emissions. It appears that this increase was due to the service rather than the vehicle use.

Seven of the ten vehicles comprising the high data point at 6600 miles had carburetor adjustments or work performed after

FIGURE 18

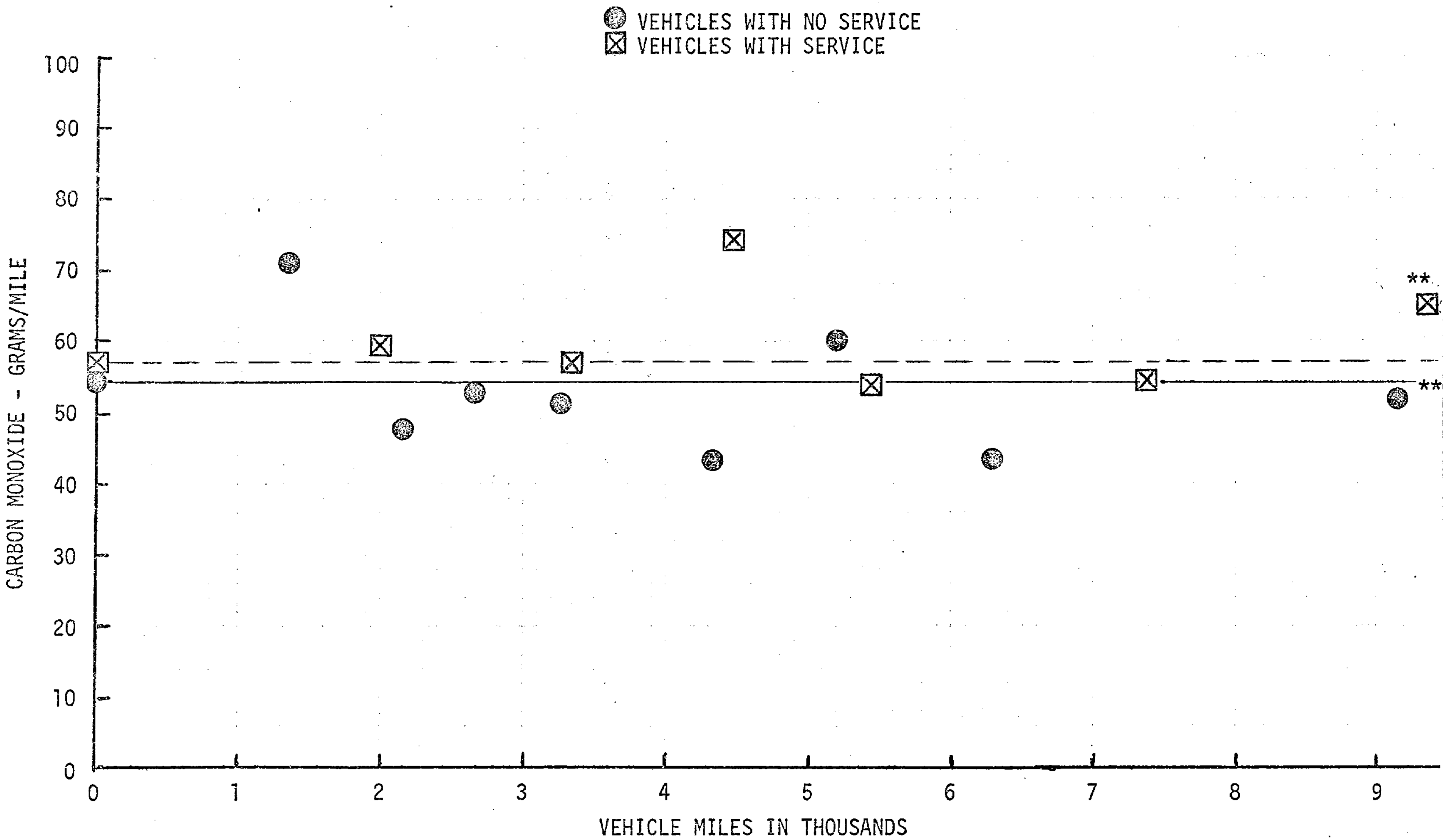
HC EMISSIONS VERSUS MILEAGE AFTER MPC TUNE-UPS ON UNCONTROLLED VEHICLES*



* EACH POINT IS AN AVERAGE OF 10 VEHICLES
** AVERAGE OF 6 VEHICLES

FIGURE 19

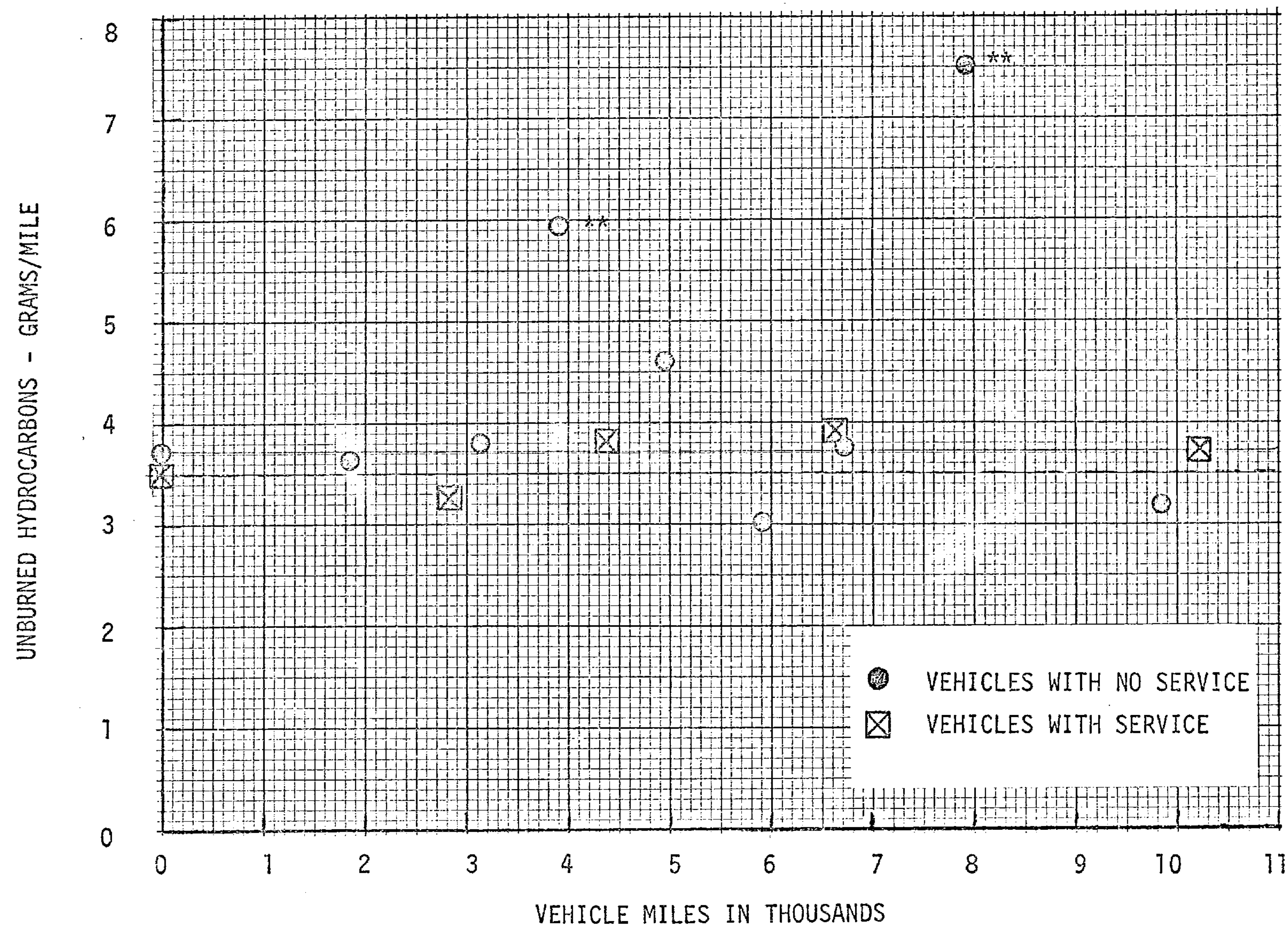
CO EMISSIONS VERSUS MILEAGE AFTER MPC TUNE-UPS ON UNCONTROLLED VEHICLES*



* Each point is an average of 10 vehicles
** Average of 6 vehicles

FIGURE 20

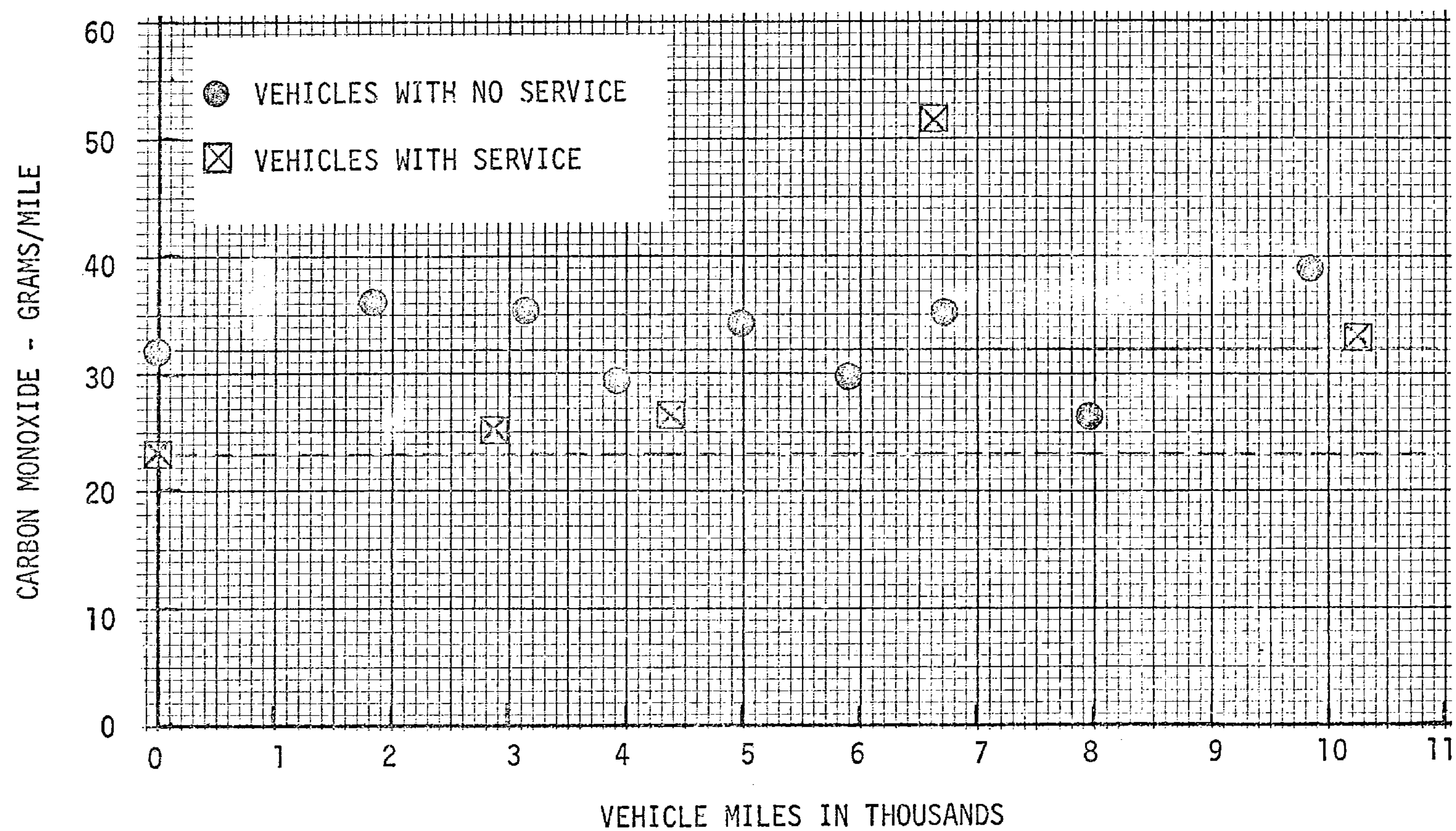
HC EMISSIONS VERSUS MILEAGE AFTER
MPC TUNE-UPS ON CONTROLLED VEHICLES *



* Each point is the average of 10 vehicles
** Includes one vehicle with oil fouled spark plug(s)

FIGURE 21

CO EMISSIONS VERSUS MILEAGE AFTER MPC TUNE-UPS ON CONTROLLED VEHICLES*



* Each point is an average of 10 vehicles

the MPC tune-up. The service on two of these seven vehicles resulted from owner complaints of poor performance. Service on the other five was done by the owner without prior notice to CARCO.

An important issue previously discussed relates to whether or not the preventative maintenance of the MPC tune-up on the lower emission vehicles that increased in emissions after tune-ups prevented a large degradation of the emissions of these vehicles. If the degradation prevention was greater than the small emission increases after tune-ups, then all vehicles should be given periodic low emission tune-ups. This program was not designed to obtain the direct answer to this question, but the data in Table 23 offers some relevant information.

TABLE 23

DEGRADATION OF HC CONTROL IN VEHICLES WITH INCREASED AND DECREASED HC EMISSIONS AFTER MPC TUNE-UPS

TYPE OF VEHICLES	NO. OF VEHICLES	CO EMISSIONS - GMS./MI.			% CHANGE AFTER MPC	% CHANGE AFTER 6 MONTHS
		BEFORE MPC	AFTER MPC	AFTER 6 MONTHS		
Decreased HC Emissions After MPC Tune-Ups	188	9.20	4.54	5.73	-50.6	-37.7
Increased HC Emissions After MPC Tune-Ups	79	4.55	6.01	5.03	+32.1	+10.5
Composite of Both Classes	267	7.83	4.96	5.52	-36.6	-29.5

The 267 vehicles returned for the six month emission tests were divided into two classes. The first class was those that decreased in HC emissions after the MPC tune-ups. The second class was those that increased after the tune-ups. It can be noted in Table 23 that the average HC emissions for the second class are only one-half of the first class. HC for the first class decreased by 50.6% after the tune-ups and after six months, this reduction was degraded to a 37.7% improvement. Conversely, the emissions from the second class increased after the tune-ups and after six months, this increase was reduced to 10.5%. The HC emissions from the second class improved with service. This indicates that the preventative maintenance aspects of the MPC tune-up may have been important in holding the emissions of this group at their low level.

One of the major reasons why the HC emissions increased on some low emission vehicles could have been that lean misfiring resulted from lean tuning. In order to explore this possibility, CO data was analyzed for the vehicles with increased HC emissions after tune-ups. This data is summarized in Table 24.

TABLE 24

CO EMISSION DATA FOR VEHICLES WITH INCREASED HC EMISSIONS AFTER MPC TUNE-UPS

TYPE OF VEHICLES	NO. OF VEHICLES	CO EMISSIONS - GMS./MI.			IDLE CO - PPM	
		BEFORE MPC	AFTER MPC	AFTER 6 MONTHS	SET BY MECHANIC	AFTER 6 MONTHS
Controlled	42	38.5	33.7	33.0	2.09	2.46
Uncontrolled	37	76.5	61.4	62.4	2.68	3.55
Composite	79	56.2	46.7	46.8	2.37	2.97
Total Fleet (Composite)	267	65.4	42.4	45.8	2.35	2.75

It is shown that the CO emissions for these vehicles did not change appreciably during the six month period. This is true for both the idle settings and the 7-mode test results. Since the 7-mode emissions decreased during the six months at no significant change in CO, the possibility of lean misfires accounting for the HC increases is questionable.

The data in Table 24 also shows that the vehicles with increased HC emissions had CO emissions that were:

(a) slightly lower than the total fleet before tune-up;

(b) slightly higher than the total fleet after tune-up; and

(c) about the same as the total fleet after six months.

This adds further substantiation that the lean misfire was probably not involved.

Table 24 also shows the degradation of the air-fuel mixture at idle for these vehicles compared to the total fleet. The increase in CO at idle from 2.37% to 2.97% for the composite of controlled and uncontrolled vehicles is not significantly different from the composite of the total fleet.

(3) Acceptance of Vehicle Owners

The acceptance of vehicle owners to MPC tune-ups was evaluated by owner interviews after six months. These inverviews were concluded with the following questions:

(a) Have you noticed a change in your car's performance?

If the answer was yes, then they were asked:

(b) Is that change acceptable to you?

If the answer was no, they were then asked:

(c) Would this change be acceptable if it resulted from a mandatory State program for reducing air pollution?

A tabulation of the results for controlled and uncontrolled vehicles is given in Table 25. It is shown that 74.5% of the vehicle owners said that an MPC tune-up was acceptable to them. 15.7% said that it was unacceptable and 9.8% stated that it would be acceptable if it were part of a mandatory air pollution control program.

It is important to note that more owners of controlled vehicles said that the tune-ups were not acceptable than did the owners of uncontrolled vehicles. This is surprising since the controlled vehicles were tuned to essentially manufacturer's specifications. The carburetor idle adjustments for the uncontrolled vehicles were not made according to manufacturer's specifications. The idle speeds were set higher and the air-fuel mixture leaner.

The owner acceptance data in Table 26 was also tabulated according to the four groups previously discussed. Group 1 vehicles received no service in six months. Groups 2 through 4 received service from either the Class A mechanics in the program, the owner, or a combination of both. The number of owners who found the MPC tune-ups unacceptable was greater for the vehicles that received service during the six months. This is expected since poor performance would motivate them toward adjustments or further repairs. Group 4 vehicle owners were the least satisfied with the tune-ups. Many of the owners in this group complained to CARCO that they were not satisfied with the results and, therefore, obtained work on their own.

The owner acceptance of MPC tune-ups appears to be satisfactory when the results from the six month interviews are compared with one month interviews with owners of vehicles with dummy VSAD kits.

TABLE 25

OWNER ACCEPTANCE OF MPC TUNE-UPS

VEHICLE GROUP	NO. OF VEHICLES	% OF TOTAL VEHICLES: ACCEPT.	NOT ACCEPT.	ACCEPT. IF MAN.
Controlled	127	33.7	9.74	4.12
Uncontrolled	140	40.8	6.00	5.62
Composite	267	74.5	15.7	9.8
		% OF GROUP		
Controlled	127	70.9	20.5	8.66
Uncontrolled	140	77.9	11.4	10.7

TABLE 26

OWNER ACCEPTANCE OF MPC TUNE-UPS
VEHICLES WITH AND WITHOUT SERVICE DURING SIX MONTHS

	NO. OF VEHICLES	% OF TOTAL VEHICLES/% OF GROUP: ACCEPTABLE	NOT ACCEPTABLE	ACCEPTABLE IF MAN.
GROUP 1 (None)	165	51.3/83	6.7/11	3.8/6
GROUP 2 (Class A Mechanic)	33	9/73	2.3/18	1.1/9
GROUP 3 (Owner)	59	13.1/60	4.5/20	4.5/20
GROUP 4 (Class A Mechanic and Owner)	10	1.1/30	2.3/60	.4/10
Composite		74.5	15.7	9.8

As discussed previously, dummy VSAD kits were placed on vehicles that did nothing to the engines. Eight percent (8%) of the owners with dummy kits stated that the change in their vehicles' performance was unacceptable.

It is difficult to obtain the "real-world" acceptance in a voluntary program. In some cases, the owners did not receive the degree of repair which they expected and were, therefore, dissatisfied. In other cases, the owners became overly critical of small differences in the vehicle's performance. The largest single owner complaint was with cold starting. When the idle mixtures are leaned, borderline and faulty chokes become obvious. This problem was not anticipated and was, therefore, overlooked in the MPC tune-up procedure. This is discussed in further detail in the next section.

7. Evaluation of the MPC Tune-Up Procedure

The MPC tune-up procedure produced greater exhaust emission reductions (initially and after six months) than previous studies would predict. However, there are two areas where improvements in the procedure could be made. The first is in reducing the number of engine defects affecting emissions that occurred during the six month test period and the second is in reducing the number of owner complaints. Both of these areas are related because many engine defects also affect engine performance. They are discussed below under separate headings.

a. Engine Defects

Table 27 lists the engine defects that occurred after the MPC tune-ups. It gives the percentage of these defects detected by diagnoses after six months of service. It is not known how many of these defects were present before or after the MPC tune-ups except the ones causing ignition misfires. Those causing ignition misfires are obvious from the 7-mode emission tests. Table 28 lists the major parts installed at the time of MPC tune-ups and gives the percentage of vehicles receiving these parts. The information in this table will be discussed in connection with analyses of defects that occurred during the six month service period.

(1) Fouled Spark Plugs

After six months of service, four vehicles or 1.3% of the total fleet had fouled spark plugs. The histories of these vehicles are given in Table 29.

The data in Table 29 shows that these misfires were not mechanic errors or a problem with the secondary ignition tester since new plugs were installed in the MPC tune-ups in all cases. The plug fouling in Cars A165 and B046 was definitely caused by excessive oil consumption. Both of these vehicles had very high mileages. The other two

TABLE 27

DIAGNOSED PROBLEMS
SIX MONTHS AFTER MPC TUNE-UPS

DEFECT	% OF CARS WITH DEFECT
Fouled Spark Plugs	1.3
Defective Ignition Wires	2.3
Lean Misfire	4.3
Plugged Air Cleaner (75% or More)	14.0
Choke Does Not Open Completely	4.7
Failed Secondary Ignition Test	32.0
Plugged PCV Valve (Less than .5 CFM)	1.0
Defective Vacuum Spark Advance Mechanism	13.0
Defective Centrifugal Advance Mechanism	1.0
Defective Ignition Points	9.0
Excessive Wear of Point Rubbing Block	3.0
Excessive Resistance in Ignition Secondary	2.7
Exhaust Valve Problem	0.7
Excessive Blow-by	4.0
Defective Choke Mechanism	3.3
Frozen Heat Riser Valve	22.0

TABLE 28

NEW PARTS INSTALLED IN MPC TUNE-UP

PART NAME	% OF VEHICLES RECEIVING PARTS
Spark Plugs	56.4
Air Filters	47.3
Distributor Points	4.4
Ignition Wires	
Complete Set	5.3
Individual Wires	7.0
PCV Valves	10.8
Carburetor Jets	3.7
Carburetor Rebuilt Kit	5.4
Replacement Carburetor	2.6
Distributor Cap	2.7
Distributor Rotor	3.0
Carburetor Choke Parts	2.0

TABLE 29

HISTORY OF VEHICLES WITH FOULED PLUGS AT 6 MONTHS

INFORMATION	CAR NUMBER			
	A041	A146	A165	B046
Year and Make	'68 Chev.	'67 Rambler	'62 Falcon	'63 Dart
Odometer Miles	64,496	65,596	95,942	103,995
Miles Driven in 6 Months	7,953	3,894	3,664	8,223
Ignition Misfire During 7-Mode Test				
Before MPC	No	No	No	Yes
After MPC	No	No	No	No
After 6 Months	Yes	Yes	?	Yes
Idle HC at 6 Months - RPM	2000+	2000+	550	2000+
Spark Plugs Installed:				
At MPC Tune-Up	Yes	Yes	Yes	Yes
During 6 Months	No	No	No	Yes

vehicles also had high mileages for their ages and the plug fouling was probably due to oil consumption. In addition to the above four vehicles needing spark plugs at six months, the plugs in two other older high mileage vehicles were installed by Class A mechanics as a result of owner complaints. These vehicles were a 1959 Ford and a 1959 Cadillac with 82,117 and 131,870 miles respectively. New plugs were installed in the 1959 Ford at the time of the MPC tune-up. The Ford failed plugs in about 1500 miles and the Cadillac failed plugs in about 5000 miles. The 7-mode emission tests on these two vehicles before MPC, after MPC, and at six months showed no plug fouling.

This brings the total vehicles known to foul plugs within six months to six out of 300 or 2%. The major cause is oil fouling which normally occurs on one or two cylinders with the highest oil consumption.

The plug fouling problem could be slightly greater than indicated by the discussion above because 12% of the vehicle owners reported that they elected to obtain tune-ups without consulting CARCO during the six month period. Most of these vehicles probably received new plugs whether they needed them or not.

Of the vehicles receiving tune-ups during the six month period, 49% of them received new plugs at the time of the MPC tune-up. The average miles traveled during the six months by vehicles which received new plugs at the time of the MPC tune-up was 7100 miles. This very high mileage is probably a strong factor that influenced these vehicle owners in their decisions to get tune-ups. The average miles traveled by all vehicles receiving tune-ups during the six month period was 6100 miles.

The previous data shows that even a six month periodic maintenance period is too long for vehicles in poor condition. On the other hand, many vehicles were driven 8,000 to 12,000 miles without any engine work and with normal six month emission tests. This suggests that quick low-cost HC tests at frequent intervals might be cost effective to single out the vehicles needing frequent maintenance.

It is concluded that the methods used to determine when to replace spark plugs appear to be satisfactory for all vehicles except those using excessive amounts of oil in one or more cylinders. Special procedures and frequent emission checks would be needed to prevent plug fouling from these engines.

(2) Defective Ignition Wires

The six month diagnoses on 267 vehicles returning for their third emission test showed that 2.3% of them had defective ignition wires. Only one of these defects (Car No. B106) was serious enough to cause a significant increase in the HC emissions during the six month

7-mode test. As shown in Table 28, the CARCO trained Class A mechanics replaced all ignition wires on 5.3% of the engines and individual wires on 7.0% of the engines. The mechanics were instructed to replace wires that:

(a) show an open circuit or excessive resistance on the oscilloscope and

(b) appear badly deteriorated and may fail within a year's service.

Of a total of 37 ignition wire repairs made on 300 vehicles (12.3%), one-third of these significantly reduced HC emissions. The HC emissions of one vehicle (Car No. A220--1959 Chevrolet) increased significantly during the "after MPC" test. The extent of the increase suggests an igntion misfire. The Class A mechanic replaced the carburetor and cleaned the air filter. His diagnosis established that ignition system repair was not required. Driveability reports by CARCO drivers and the owner after the MPC tune-up showed no demerits. The two week interview revealed that the owner was "very pleased". It is assumed that in the process of changing fuel lines for measuring fuel consumption during the 7-mode test that the ignition wires were shorted out on one cylinder.

It is concluded that the methods employed to detect defective ignition wires in the MPC tune-up procedure are adequate to eliminate high HC emissions from misfires and to prevent 99.7% of the misfires from occurring during 5000 miles of service. If the period between tune-ups was one year rather than the six months used in this study, more emphasis may be needed on the task of inspecting wires and replacing those which may deteriorate within the one year period. Wires in marginal condition usually perform satisfactorily until they are disturbed by work on the engine, such as checking the oil and tune-up repairs.

(3) Lean Misfire

The six month diagnoses showed that 13 or 4.3% of the test vehicles had lean misfires at idle. Test data on these vehicles are given in Table 30. About one-half of these were serious enough to cause a significant increase in HC and a noticeably rough idle. They were apparently caused by leaning of the carburetor air-fuel ratio during the six month test period in all cases except two. The average CO reading at idle decreased from 2.0% to 0.7%. The lean misfires on the two vehicles which did not become lean could have been caused by the development of air leaks in the intake manifole or a deterioration of the ignition system. An engine with a good ignition system will accept leaner air-fuel mixtures than one with an ignition system in poorer condition. Therefore, a lean misfire can develop even though the air-fuel mixture remains the same. Usually carburetion becomes richer with mileage and, therefore, compensates for ignition system deterioration but not in all cases.

TABLE 30

LEAN MISFIRES IN ENGINES FROM SIX MONTH DIAGNOSES

CAR NO.	YEAR AND MAKE	7-MODE EMISSIONS Grams/Mile				NO LOAD EMISSIONS HC-PPM/CO-%					
		HC		CO		HC @ IDLE		HC @ 2500 RPM		CO @ IDLE	
		After MPC	After 6 Mos.	After MPC	After 6 Mos.	After MPC	After 6 Mos.	After MPC	After 6 Mos.	After MPC	After 6 Mos.
A004	1969 Mercury	2.94	2.71	21.5	17.1	200	210	100	45	.8	.2
A087	1970 Dodge	3.39	2.18	18.7	16.5	190	200	60	40	1.0	.2
A154	1964 Mercury	3.01	4.13	55.0	43.8	100	375	50	110	1.0	.4
A174	1969 Volkswagen	2.29	6.43	21.8	42.5	220	500	190	100	2.4	3.0
A187	1965 Chevrolet	7.96	7.13	31.5	28.2	550	1250	350	390	2.0	.4
A226	1966 Oldsmobile	2.08	2.83	36.9	7.28	120	200	90	130	3.0	.2
B020	1970 Chevrolet	3.32	4.20	30.7	32.0	170	1000	80	100	1.4	.8
B022	1965 Ford	6.76	7.71	75.0	21.6	350	2000	280	450	2.7	.2
B029	1964 Ford	3.51	9.73	31.5	17.6	345	2000	170	320	2.5	.6
B035	1970 Oldsmobile	2.27	3.67	22.6	22.9	130	300	30	40	1.6	1.5
B063	1966 Ford	2.46	2.15	31.9	27.4	260	2000	120	1125	3.1	.4
B105	1960 Chevrolet	5.44	6.40	26.2	24.1	380	1100	180	200	1.7	1.1
B109	1962 Ford	3.37	12.0	42.1	34.4	380	1450	120	1150	2.7	.1
	AVERAGE	3.75	5.48	34.3	24.5	261	968	140	323	2.0	0.7
	% CHANGE	+46		-28		+270		+130		-65	

*B109 may also have a problem with valves

As shown in Table 30, the average exhaust emissions from these vehicles (measued under 7-mode test cycle conditions) increased 46% while the CO decreased 28%. The HC emissions at idle increased 270%. Based upon the 7-mode test cycle, the lean misfires that developed increased HC emissions of the total fleet by about 2%. This suggests that the idle adjustment specifications of the MPC tune-up procedure could be improved by richening them slightly.

An examination of vehicles that slightly increased in HC emissions after the MPC tune-up showed that this increase was probably not due to lean misfire. It is concluded that the MPC tune-up procedure specifications for idle adjustment are adequate to prevent lean misfire on engines with good ignition systems.

Domestic post-1965 engines with the "engine modification type" controls with good ignition systems and no air leaks in the intake manifold will usually operate at idle without misfire at a minimum CO range of .5% to 1.0%. Older engines without "engine modification type" controls will usually operate in a range of 1.0% to 2.0% CO without lean misfire. The specifications for the MPC procedure were set at 1.0% to 2.0% for "engine modification type" controlled engines and 2.0% to 3.0% for domestic engines without these controls.

In California where the major vehicle pollution problem is HC and NO_x, it appears that the MPC tune-up procedure should be amended to provide slightly richer carburetor setting at idle for better HC and NO_x control at the expense of slightly higher CO emissions. There are limitations to richening this specification because HC will increase when the air-fuel ratio is decreased below a certain value. Based upon the results of this study, the MPC tune-up procedure would be improved for California use if the idle adjustment specifications were increased by 0.5% CO.

(4) Plugged Air Filters

The plugging of air filters causes increased exhaust emissions by enrichment of the fuel-air mixture. The primary effect is on CO, but highly plugged filters will also increase HC. The Class A mechanics were instructed to replace air filters if they were more than 50% plugged. New air filters were installed on 47.3% of the vehicles. After an average fleet mileage of 5283 miles, 14% of the vehicles had air filters that were plugged 75% or more. Two percent (2%) of this 14% started with new filters and were driven an average of 6268 miles. The other 12% of this 14% did not have new filters and were driven an average of 5819 miles.

This data shows that the air filters on a small percentage of vehicles operating in the Los Angeles area plug quite rapidly. This plugging could begin to affect emissions in as few miles as 5000. On the other hand, 10% of the vehicles with new filters operated over

8000 miles without reaching the 75% plugging condition. The balance of the total fleet (86%) operated an average mileage of over 5000 miles without reaching the 75% plugging condition.

It is concluded that the replacement criteria in the MPC tune-up procedure is acceptable for annual tune-ups. The additional inspection of air cleaners at a time of oil changes would help eliminate the plugging of filters on vehicles which either plug more quickly or are used in atmospheric conditions of high particulate concentrations.

(5) Defective Carburetor Chokes

Defective chokes cause excessive exhaust emissions in two ways. The first way is that they will cause an unnecessary enrichment of the fuel-air mixture if the choke does not open fully when the engine is warmed up. The primary effect is to increase CO and the secondary effect is to increase HC if the problem is severe. The six month diagnoses on the MPC test fleet showed that 4.7% of the vehicles had chokes that did not open completely. Most of these vehicles were of the uncontrolled group and the choke opening varied from 75% to 95%. The average CO emissions of ten vehicles in this group were 84.5 grams per mile compared to 83.4 grams pey mile for all vehicles. This indicates that this small amount of choke restriction did not affect the CO emissions at the relatively low power conditions of 7-mode test cycle.

The second way that chokes can cause excessive emissions is the malfunction of the mechanism. Common malfunctions are broken linkages and a stuck choke blade. Excessive emissions are produced by repeated stalling and restarts, pumping of the accelerator, and lean misfiring. At six months, 3.3% of the vehicle fleet had choke mechanisms which did not operate properly. As shown in Table 28, the Class A mechanics repaired 2.0% of the chokes at the time of the MPC tune-up. Indicated changes in the MPC tune-up procedure regarding choke repair and adjustments are discussed in futher detail in Section III,B,7.

(6) Failed Secondary Ignition Test

A secondary ignition tester previously described in Section III,B,2 was primarily used at the time of MPC tune-ups to determine if spark plugs would operate for approximately one year or about 10,000 miles without fouling. New plugs were installed in engines failing this test. It is reasonable that 32% of the vehicles would fail this test after an average mileage of 5283 for the test fleet.

(7) Plugged PCV Valves

Plugged PCV valves is another engine defect which causes emission increases due to the enrichment of the air-fuel mixture. Most PCV valves flow blow-by gases at 2.0 to 3.5 CFM at idle. The six month diagnoses showed that three vehicles or 1% of the total fleet had PCV valves that were plugged. One was completely plugged and the two flowed gases at

.5 CFM or less. These were probably missed by the Class A mechanics at the time of tune-ups. The mechanics were instructed to flow PCV valves if the crankcase pressure was not negative (in other words, the PCV valve flow rate is not sufficient to handle the blow-by gases). If the flow test was satisfactory, they were instructed to clean the PCV valve. If the flow rate test was unsatisfactory, they were instructed to install a new valve.

As shown in Table 28, 10.8% of the PCV valves were replaced at the time of the MPC tune-up. It appears that the MPC tune-up procedure is adequate since the plugging was reduced by about 90%.

(8) Defective Spark Advance Mechanisms

Thirteen percent (13%) of the vehicles had defective vacuum advance mechanisms. The primary mode of failure was ruptured diaphragms in the actuator. One percent (1%) of the vehicles had defective centrifugal advance mechanisms. A combination of both of these defects (or the installation of a retrofit device employing the disconnection of vacuum spark advance) and the centrifugal advance defect would result in extremely high exhaust temperatures. These exhaust temperatures would likely result in engine damage in the form of burned exhaust valves or cracked exhaust manifolds.

(9) Defective Ignition Points

Nine percent (9%) of the vehicles had defective distributor points after six months of service. The criterion for determining that the points were defective was a malfunction observed on the oscilloscope. If the criterion was a subjective observation of point condition, many more sets of points would have been judged defective. The lack of replacement of defective or marginal distributor points is a major problem with the MPC tune-up procedure. Distributor point replacement was purposely de-emphasized because most mechanics automatically replace spark plugs, points, and condenser with every tune-up. In most cases, the points and condenser will outlast two or three sets of plugs.

The MPC tune-up procedure should be changed to include a visual inspection of points on every engine and not just when the oscilloscope diagnosis indicates a problem. The distributor points were replaced on 4.4% of the vehicles at the time of MPC tune-ups. The six month inspection indicates that about four times more points should have been replaced. This would result in the replacement of points about once for every three changes in spark plugs.

(10) Excessive Wear of Point Rubbing Block

Excessive wear of the distributor point rubbing block usually occurs because the mechanic does not properly lubricate the distributor cam. This also wears the distributor cam which is a more serious problem. The six month diagnoses showed that 3.0% of the engines had inadequate lubrication and/or wear of the point rubbing block. The MPC procedure should be changed to include the inspection and lubrication (as required) of the distributor cam at the time of the distributor point inspection stated above.

(11) Exhaust Valve Problem

The Class A mechanics were instructed to reject any vehicle from the program which had burned exhaust valves. In general, they did a good job at this task. This is discussed in further detail in the next section. The six month diagnoses indicated that two Volkswagens had valve problems. These valve problems resulted in high HC emissions at idle and slightly abnormal HC emissions under the 7-mode test conditions. The problems could have been either burned valves or, more likely, improper valve lash.

(12) Excessive Blow-by

Excessive blow-by indicates that the piston rings are worn or not sealing properly. Vehicles entering the program were not rejected because of excessive blow-by. At the end of the six month period, 4% of the vehicles had excessive blow-by. The major problems with these engines are that:

(a) the excessive oil consumption will cause spark plugs to foul, and

(b) the blow-by gases exceed the capacity of the PCV valve and can foul the carburetion and plug the air filter.

(13) Frozen Heat Riser Valves

A great many vehicles have frozen heat riser valves. This defect affects emissions because the engine does not warm up properly. These valves operate in the corrosive atmosphere of exhaust gases and are difficult to lubricate. Many valves are frozen so hard that it requires considerable time to free or replace them. This is usually not a cost-effective emission control repair. The repair guidelines of the MPC tune-up procedure allow five minutes to free-up frozen valves.

At the six month inspection, 22% of the vehicles had frozen heat riser valves. It is difficult to determine if these valves were (1) freed up at the time of the MPC tune-up, (2) overlooked by the mechanic, or (3) required more time to free-up than five minutes. It is also difficult to determine if the procedure should place more emphasis on these valves. Since cold start problems were the largest owner complaint, the effect of heat riser valve operation on warm-up performance should be studied further.

b. Owner Complaints

The vehicle owners who participated in the program were instructed not to have any work performed on their engines for six months unless they contacted CARCO first. They were informed that CARCO would diagnose any problems which they may have; and if these problems were associated with the work performed in the program, CARCO would take care of them. These instructions were necessary to maintain control over the fleet for the six month degradation study and to also document any problems. Since the owners were not told exactly what work was performed on their engines, they reported a large number of problems not associated with the tune-ups. The investigation of many complaints resulted in the finding of defective batteries, starters, cooling systems, etc.

A major bonafide complaint was cold starting problems arising from leaning out the carburetion. Some of the chokes were defective or marginal. Others needed to be richened to compensate for the leaning. Part of this problem could be alleviated by emphasizing to the mechanics that the choke must be operative and free. The vehicle owners should be also alerted of the possible problem and be instructed to test the cold start performance. If it is unsatisfactory, return the vehicle for a minor choke adjustment.

A second less frequent complaint was that the engine lacked power. In most cases, the owners were content to "live with the problem". In others, it was necessary to richen the idle mixture very slightly. In still other cases, it was obvious at the six month inspection that the owners adjusted the carburetors themselves.

A few complaints resulted in hard starting and engine malfunctions due to faulty distributor points. These complaints could be probably eliminated by a procedure change previously discussed.

Some owners complained about the faster idle speed adjustment on pre-1966 vehicles. They thought that the engine was using too much gasoline. Faster idle speeds is the principal cause of dieseling when the key is shut off. The idle speeds specified by the MPC tune-up procedure are adequate for lean operation and yet prevent dieseling. In cases where dieseling was reported, the vehicles either had engine controls requiring higher speeds than the MPC specifications or the idle speed was higher than the MPC specifications.

Most owner complaints were received immediately after the vehicle was returned to the owners and were reflected in driveability questionnaires. These results were presented earlier in Section III,B,6. Several of these complaints could have been alleviated if the Class A mechanics would have road tested the vehicles. This point was covered in the training course but should be made part of the MPC tune-up procedure.

c. Indicated Changes in Procedure

Changes in the MPC tune-up procedure indicated by the performance of the program are listed below:

(1) Give special attention to proper choke operation when the carburetion is leaned. Where possible, try a cold start after tune-up. Advise the owner of a possible problem and ask him to return the vehicle for minor choke adjustments as required.

(2) Remove the distributor cap on every engine to inspect contact points and cam lubrication.

(3) Increase the adjustment goals for idle CO at idle by 0.5%.

(4) Increase the carburetor repair guidelines for the 2500 RPM CO test by 0.5%.

(5) Instruct owners of engines with excessive blow-by and/or other indications of high oil consumption to replace spark plugs frequently.

(6) Expand on the inspection and preventative maintenance of ignition wires.

(7) Road test every vehicle before delivery to the owner.

The reasons for all of the above changes were previously discussed except for item (4). This change results from problems that the Class A mechanics encountered in changing carburetor jets. Most mechanics did not have the experience to perform this change quickly and without errors. The availability of carburetor jets was also a problem.

A 5% increase in the repair criterion consisting of the CO value measured at 2500 RPM would reduce the number of carburetors requiring repair. This would decrease the amount of CO reduction but should not affect the HC emission. An analysis of the test data indicated that many jet changes did not significantly affect the HC emissions even though a large reduction in CO was attained.

In California where HC (and not CO) is the main problem, the relaxation of the CO repair guidelines should be a cost-effective change. A relaxation greater than 0.5% may be acceptable; however, further testing directed specifically to this problem would be needed to be certain that HC control is not compromised.

8. Evaluation of Mechanic Training

Some of the vehicle problems relating to inadequate mechanic training and mechanic errors have been discussed previously. In many areas, it is difficult to clearly establish a single cause of problems. It is more likely that a combination of errors and circumstances were involved in most problems.

a. Training Errors and Indicated Improvements

During the course of the program, a few errors and omissions in the training of mechanics became apparent. The first error encountered was that some of the mechanics were "oversold" on the emission control advantages of lean carburetor settings. This became obvious to the mechanics when vehicles with owner complaints were returned to them.

A second error was that too much emphasis was placed on the fact that the service industry installs too many new distributor points. Most of the mechanics were so convinced that they did not visually inspect the points unless a malfunction occurred on the oscilloscope. This resulted in the replacement of points on only 4.4% of the vehicles.

Another problem with the training course was that the mechanics should have been given more laboratory training in carburetor repair. This was especially true since the carburetor repair guidelines called for the repair of about 15% of the carburetors.

Greater emphasis should have been placed upon the importance of ignition misfires. This point was one of the major areas of training, but it could be given even more emphasis by citing the HC emission results of this program. Diagnostic and preventative maintenance techniques should be expanded to isolate and help prevent impending ignition misfires.

Greater emphasis should have been also placed upon the importance of road testing vehicles. A standard road test procedure should be developed and the mechanics taught how to perform it. A list of typical driveability problems and corresponding solutions should be also prepared. One of the reasons why more mechanics did not road test completed vehicles was that this program was conducted during the summer months. At this time, tune-up business is at a maximum and the mechanics did not have sufficient time to work on the vehicles of their regular customers and the program vehicles as well.

During the diagnoses of the program vehicles after six months of service, it became apparent that the correct diagnosis of exhaust valve problems is a very difficult task. This is due to the fact that the following engine defects affect the engine in a similar way:

(1) Open circuits in the ignition secondary system, such as ignition wires.

(2) Fouled spark plugs.

(3) Misfire due to lean mixtures caused by unbalanced carburetion, a vacuum line leak and leaks at the intake manifold gaskets.

(4) Defective piston rings.

(5) Defective pistons.

(6) Exhaust and/or intake valves that stick open at idle due to valve stem deposits.

(7) Maladjusted valve lash.

(8) Defective hydraulic valve lifters.

(9) Worn cam shaft lobes.

The CARCO Class A mechanic performing the six month diagnoses was asked to comment on vehicles with possible exhaust valve problems. A data summary from diagnostic sheets and emission tests for 21 vehicles which the mechanic selected with possible burned valves is shown in Table 31. This data is shown to illustrate the point that it is difficult to diagnose valve distress. The power test is commonly used to determine possible valve problems or other defects. If the ignition system is good and there are no lean misfires, the next step is to perform a compression pressure check on the suspect cylinder.

If the mechanic has an infrared instrument to measure HC in the exhaust, a high reading at idle and a lower reading at a higher speed is an excellent diagnostic method. Since 7-mode test data was available for these vehicles, it was very useful in making the diagnoses. Compression checks were not made which would have supplied the maximum amount of information--short of removing the cylinder heads for inspection.

It is interesting to note that only three of the twenty-one vehicles probably had valve problems. Two of these were Volkswagens which historically give uneven power test results and also uneven compression test results. This is due to the dependence on close tolerance mechanical valve lash settings. These engine valves could have been okay and the valve lash settings out of tolerance. Nevertheless, the engines appeared to have valve problems causing emission increases.

Most of the other problems pointing to possible valve problems were due to either ignition or lean misfires. Vehicle B030 would be difficult to diagnose without the 7-mode test data because ignition and lean misfires were not present and yet the power from the cylinders was uneven. The no-load HC emissions were very high. Since the loaded 7-mode emission test showed reasonable HC emissions, the engine must have had sticking valves which hung open at no-load but closed under the pressures of load.

TABLE 31

DIAGNOSES AND EMISSION DATA ON VEHICLES WITH POSSIBLE BURNED VALVES

CAR #	YEAR & MAKE	7-MODE EMISSIONS-HC GRAMS/MILE AFTER TUNE-UP	AFTER 6 MOS.	VSA MECHANISM	HC @ NO LOAD PPM IDLE	2500 RPM	POWER TEST ON CYLINDERS	IGNITION SYS.	IDLE CO - %	CONCLUSIONS
A011	'69 VW	6.77	11.7	Good	2000	475	#2 Cyl. low on power	Okay	8.0	Valve problem
A041	'68 Chev.	2.88	49.2	Good	2000	2000	#6 & #7 Cyls. = 0	2 Fouled Plugs	1.1	Ignition Misfire
A059	'68 VW	6.13	4.18	Good	200	70	#4 Cyl. low	Marginal	1.5	No Problem
A079	'68 Ply	2.73	3.02	Good	2000	2000	#2 Cyl. = 0	Bad Wires	1.4	Ignition Misfire
A087	'70 Dodge	3.39	2.18	Good	200	40	Uneven	Okay	.2	Lean at Idle
A118	'63 Ford	6.43	7.88	Good	450	75	#6 Cyl. Low	Okay	6.8	No Problem
A146	'67 Rambler	3.48	25.2	Good	2000	1600	#4 Cyl. = 0	Fouled Plug	2.6	Ignition Misfire
A202	'67 Datsun	6.55	7.06	Good	700	220	Uneven	Open Secondary	3.8	Ignition Problem
A204	'57 Cad.	5.52	5.22	Good	420	190	#7 Cyl. Low	Marginal	2.0	No Problem
A205	'59 Mercury	3.08	4.54	Bad	350	100	Uneven	Okay	1.0	Lean Misfire
A211	'60 Ford	7.91	6.85	Good	400	550	#1 Cyl. Low	Okay	1.0	No Problem
A214	'60 VW	3.02	9.96	Good	2000	400	2 Cyls. Low	Okay	7.4	Valve Problem
A216	'63 Chev.	7.41	4.78	Good	800	200	#4 Cyl. Low	Marginal	4.8	Misfire
A226	'66 Olds.	2.08	2.83	Good	200	130	#8 Cyl. Low	Okay	.2	Lean Misfire
B020	'70 Chev.	3.32	4.20	Good	1000	100	Slightly Uneven	Okay	.8	Lean Misfire
B009	'64 Ford	3.51	9.73	Good	2000	320	#6 Cyl. Low	Okay	.6	Lean Misfire
B030	'64 Chev.	4.52	6.96	Good	1900	1400	Uneven	Okay	1.6	Sticking Valves
B046	'63 Dodge	4.41	20.6	Bad	2000	2000	#3 Cyl. = 0	Fouled Plug	8.4	Ignition Misfire
B105	'60 Chev.	5.44	6.40	Good	1100	200	Uneven	Okay	1.1	Lean Misfire
B106	'59 Chev.	5.54	26.2	Good	1500	2000	#7 Cyl. = 0	Misfire	1.6	Ignition Misfire
B109	'62 Ford	3.37	12.0	Bad	1450	1150	#4 Cyl. Low	Okay	.1	Lean Misfire & Valve Problem
	AVERAGE	4.64	11.0							

In this program, 141 1966 thru 1970 vehicles and 159 1957 thru 1965 vehicles were first tested at the ARB Montebello test station and then sent to one of the ten Class A stations for tune-ups. The Class A mechanics in these stations were instructed to reject any vehicles with burned exhasut valves. Eight (8) vehicles of the pre-1966 group were rejected. Emission and mechanic data for these vehicles is shown in Table (Section III,B,6).

It is important to note that the average HC emissions for these rejected vehicles is only 16.5 grams per mile compared to 10.8 grams per mile for 1959 vehicles not rejected. It is interesting that the emissions for vehicle nos. A088 and B071 were only 6.26 and 9.88 respectively even though the Class A mechanics reported no compression in cylinders. These were probably sticking valves.

Two of the vehicles from Table 31 were given "valve jobs", retested, tuned-up, and retested after six months. The results are given in Table 10 (Section III,B,6). Vehicle B009 was apparently diagnosed improperly because the emissions were reasonably low at the start and decreased only slightly with the "valve job". It is important to note that after six months, this vehicle was again picked out by the CARCO mechanic doing the final diagnosis (Table 31) as one with possible bad valves. Lean misfire was the problem at six months. The second vehicle--A163--did have defective valves and the HC emissions decreased accordingly from 17.5 to 5.5 grams per mile.

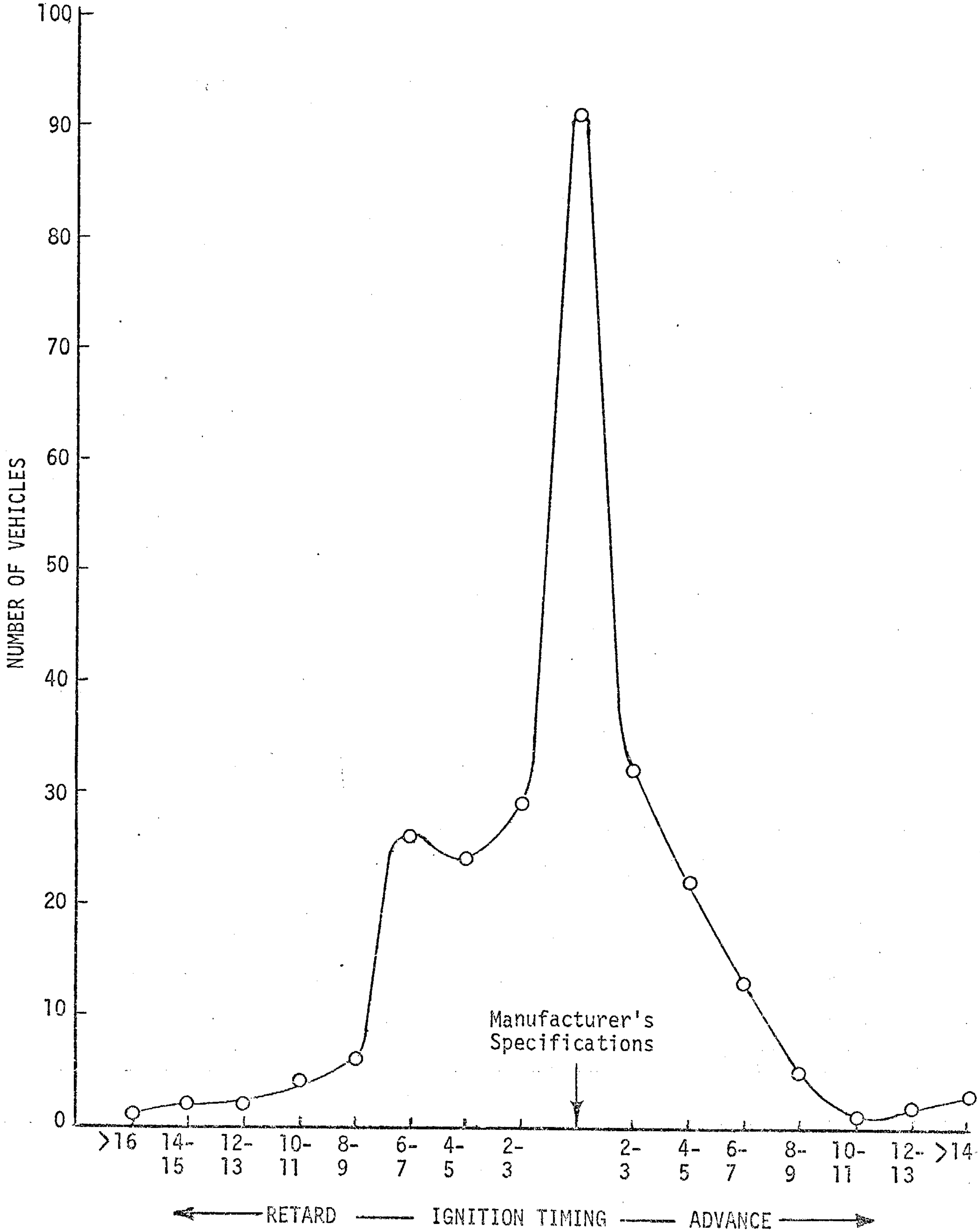
Only one 1966-1970 vehicle was rejected out of 141 vehicles. The HC emissions for this vehicle--B096--was 4.70 grams per mile compared to 4.82 for the average of 141 vehicles. The diagnosis was based upon a low power test on cylinder #1 which later showed a compression of 90 psi compared to other cylinders of 135 to 150 psi. The valve was probably sticking at idle. The no-load HC measurements were 600 ppm at idle and 210 ppm at 2500 RPM.

In light of the above discussion, the training course should include a special session on the diagnosis of valve problems. It is obvious that many expensive "valve jobs" are probably being needlessly performed because of improper diagnoses. HC and CO infrared meters are extremely valuable tools in the proper diagnosis of potential valve problems.

Another area of concern which relates to mechanic training is ignition timing. The six month diagnoses showed that the basic timing on only 35% of the vehicles was at manufacturer's specifications plus or minus one degree. Thirty percent (30%) of them were advanced an average of 5 degrees and 35% of them were retarded an average of 5 degrees. A distribution curve showing the extremes of maladjusted timing is shown in Figure 22. The fact that the timing was not according to manufacturer's specifications does not prove that the Class A mechanics set it improperly, but it is reasonable to expect that some of this problem was caused by mechanics' errors. Other factors that could cause the improper timing include:

FIGURE 22

DISTRIBUTION OF BASIC SPARK TIMING ON TEST FLEET SIX MONTHS AFTER MPC TUNE-UPS



(1) Faulty timing lights

(2) Distributor point rubbing block wear

(3) Distributor point deterioration

(4) Readjustment by the owner or another mechanic

Mechanic errors that could result in improper timing are:

(1) Obtaining the wrong timing specifications.

(2) Reading the wrong marks on the timing pulley or pointer.

(3) Neglecting to set the timing.

The training course should point out the above problems in maintaining the proper ignition timing.

b. Mechanic Performance

Previous discussions of mechanic training and indicated improvements in the MPC tune-up procedure referred to mechanic performance also because these subjects are so closely related.

The mechanic's working environment and duties have a large influence on his performance as a tune-up mechanic. In some shops, Class A mechanics are assigned to different jobs and they do not gain the specialized experience needed to become an expert diagnostician. The "programmed" tune-up approach used in this study tends to compensate for the lack of experience, but a top diagnostician is extremely valuable for vehicles with unusual problems.

The capabilities of all the ten Class A mechanics trained in this program were quite adequate to satisfactorily perform the MPC tune-ups. Their performance as measured by good emission reductions at low costs supports this statement.

The main objective of the training course was to convert the mechanics to first think in terms of exhaust emissions whenever they diagnosed or adjusted an engine. The current thought pattern of most mechanics is to:

(1) Replace the customary tune-ups parts

(2) Check the engine out on the oscilloscope

(3) Use instruments to make the proper adjustments

A better thought pattern for low-emission tuning at reasonable prices it to:

(1) Use the instruments to first determine what repairs should be made.

(2) Make only those repairs required to keep emissions down for one year.

(3) Perform preventative maintenance on parts that can cause emission increases.

(4) Use instruments to make the proper adjustments and achieve low emissions.

A well-trained and experienced tune-up mechanic will recognize immediately the great value of the HC and CO meters in diagnosing engines. His <u>first</u> thought will be to insert the exhaust probe to see what the emissions will tell him.

9. Conclusions

The following conclusions are drawn from Section B of the Technical Discussion:

a. Upgrading the service industry with diagnostic equipment and training Class A mechanics to perform MPC tune-ups would provide significant and cost-effective emission reductions of about 38% HC and 35% CO. The NO_x emissions would increase by about 5%.

b. The combined use of low-emission tune-ups and preventative maintenance procedures (MPC tune-up) by an upgraded service industry (every six months or every 5000 miles) would maintain both HC and CO emission levels at about 30% less than the current levels. NO_x levels would be about 4% higher.

c. The average cost for the first tune-up would be about $27.50. If the interval between tune-ups were six months, this cost would reduce because the $27.50 includes the replacement of parts needed for a year's service. If the interval between tune-ups is one year, the $27.50 figure would increase to $30-$35 to account for unforeseen problems that would develop during the year.

d. California's Class A mechanics can be trained and motivated to competently perform low-emission tune-ups in a 40-hour course.

The ten mechanics trained in this program responded well to the "programmed" procedure approach and the concept of only repairing parts that were defective or may become defective within one year. It appears that mechanics can be motivated by having training and by having their work inspected by government inspectors who can require them to perform according to a specified procedure.

e. Tuning pre-1966 vehicles to lower emission adjustment specifications than those provided by the engine manufacturer produced higher and longer lasting emission reductions and was more acceptable to owners than tuning controlled vehicles to manufacturer's specifications.

f. The cost effectiveness of MPC tune-ups on pre-1966 vehicles is extremely good and is four times better than MPC tune-ups on 1966 to 1970 vehicles.

g. The owner acceptance of MPC tune-ups is satisfactory.

h. Degradation of the control provided by MPC tune-ups was much lower than that predicted by other studies, even though the vehicles were driven more than the average.

i. The largest cause of degradation was spark plug fouling in engines with excessive oil consumption. These engines rapidly become extremely high emitters.

j. Engine maintenance requirements for good emission control vary greatly with vehicle condition and the type of service. Some vehicles in poor condition need attention about every 5000 miles while the newer vehicles maintain emissions satisfactorily for up to 15,000 miles.

k. Burned or defective exhaust valves increase the passenger vehicle contribution to HC emissions by only about 2.5%.

l. The MPC tune-up procedure can be improved by:

(1) Richening up the carburetor adjustments and allowing richer operation in the repair guidelines to provide equal HC control, fewer carburetor repairs, a small loss in CO control, and better driveability.

(2) Including a more thorough inspection of choke operation and making adjustments as indicated by cold starts.

(3) Adding a visual inspection and the required repair of all distributor points.

(4) Requiring a post-tune-up road test.

The program was not designed to determine if all vehicles should be given periodic MPC tune-ups or only a portion of them that were rejected by an inspection test. The program did produce information relating to this question, but it is not conclusive. About 30% of the lower emission vehicles increased in HC emissions immediately after the MPC tune-ups. The key question is related to whether or not the preventative maintenance performed on these vehicles decreased the degradation of the emission levels of these vehicles more than the tune-ups increased them initially. Degradation data on the vehicles that increased with the MPC tune-up showed that their emission levels decreased with time rather than increased. This indicates that all vehicles should be periodically tuned.

On the other hand, analysis of the data shows that nearly all of the emission decreases can be attained by emission testing all of the vehicles and only tuning the highest emitting 50%. It is not known how much the untuned vehicles would have degraded during six months or, therefore, what the emission level of the total fleet would be in six months.

C. THE VSAD APPROACH TO NOX CONTROL

The vehicle owner acceptance and possible side effects of disconnecting the vacuum spark advance of engines were evaluated with three difference groups of vehicles. For simplicity, these groups are referred to as "B", "C", and "D". Each group was selected to be representative of the California population of 1957 through 1970 vehicles. The "B" group consisted of 100 vehicles from the 300 vehicles which were previously given MPC tune-ups. VSAD kits were installed two weeks after the tune-ups.

The "C" group consisted of another 100 vehicles of the same makes and models as the 100 "B" vehicles. No other work was performed on the "C" vehicles except the installation of VSAD kits.

The "D" group of vehicles was selected to be representative of the "B" and "C" vehicles. Dummy kits which only appeared to disconnect the vacuum to the distributor were installed on these vehicles. The dummy vehicles were placed in the program to help separate owner bias from meaningful test results.

The 100 "B" vehicles were included in the program to determine if VSAD would be more or less acceptable in vehicles in a state of good repair.

1. Program Operations

The VSAD approach to NO_x emission control was evaluated by:

a. Procuring GM VSAD-type emission control kits for cutting off the vacuum to the distributor when the engine coolant temperature is below 205°F.

b. Reworking the interior of the GM kits to provide 50 "Dummy" kits.

c. Preparing kit instructions.

d. Training 10 Class A mechanics to install the kits.

e. Selecting and soliciting 150 vehicles representative of the California population of 1957 through 1970 vehicles. (100 vehicles were available from the MPC tune-up portion of the program.)

f. Installing the kits and performing driveability tests before and after kit installations.

g. Removing the kits after one month of service and performing driveability tests before and after kit removals.

h. Interviewing the vehicle owners after one month to obtain their comments and acceptance of the kits.

The actual program sequence completed with these groups of vehicles is shown in Tables C-8 and C-9 in Appendix C. As shown in these tables, the vehicle owners were also given questionnaires to determine their opinions and comments on how their vehicles performed before and after the kits were installed. A third questionnaire was mailed back after the kits were removed to determine if the owners observed the reverse of any effects which they previously noted. This questionnaire is shown in Table C-2 in Appendix C. CARCO technicians also performed driveability tests before and after kit installations and removals. The CARCO driveability tests were performed in accordance with the form shown in Table C-3 in Appendix C.

Interviews with the owners were conducted one month after the installation of the kits to obtain the answers to questions regarding the performance of their vehicles and to obtain any unsolicited comments on the side effects of the VSAD kits. The form used for this interview is shown in Table C-5 in Appendix C.

Owner complaints which occurred within the one month period were handled according to the ground rules listed in Table D-3 in Appendix D.

2. Selection and Solicitation of Test Vehicles

The vehicles for the evaluation of the VSAD approach to NO_x control were selected by taking a representative sample of 50 and 100 vehicles from the 300 vehicle sample selected for the evaluation of the MPC tune-up approach to HC and CO control. These smaller groups have the same distribution as the 300 vehicles except the Volkswagens were deleted. VSAD kits cannot be installed on Volkswagens because their engines have no centrifugal spark advance. Tabulations of the 50 and 100 vehicle groups are shown in Table D-4 and D-5 in Appendix D.

Vehicles for the VSAD evaluation were solicited by the same methods as for the MPC tune-ups. These methods are described in Section III,B,5. The vehicle owners were not informed of the specific work to be performed on their engines. The vehicles in groups B, C, and D were matched insofar as possible by make and model year to more accurately evaluate the effects of VSAD.

3. VSAD Kit Installation

The ten Class A mechanics trained to perform MPC tune-ups were also trained to install the VSAD kits. The kit installation is simple and, therefore, the training required less than one hour. The kit is installed by cutting the top coolant hose between the engine and the radiator. A brass sleeve containing a thermally actuated switch is installed in this line. The simplest installation involves the rearrangement of vacuum hoses to place this thermally actuated switch in the vacuum line leading to the distributor vacuum advance mechanism. If the coolant temperature exceeds 205°F, the switch opens and full vacuum spark advance is attained.

Most post-1965 vehicles obtain the vacuum source to the distributor from a "ported" connection in the carburetor. In these cases, the engine has no vacuum advance at idle. When VSAD kits are installed on these vehicles, a new source of full manifold vacuum is found to give complete vacuum advance at idle in case of engine overheating. In these cases, the engine is provided with better cooling at idle than before the kit installation. The connection of full vacuum advance at idle (when the switch reaches 205°F) causes the engine to speed up, thus increasing the speed of the fan and water pump. Exhaust gas temperatures will also decrease.

The installation instructions supplied to the Class A mechanics are shown in Table C-10 in Appendix C. Special precautions were taken to prevent the mechanics from disturbing carburetor mixture adjustments previously made on the "B" group of vehicles with MPC tune-ups. This could not be avoided in all cases because the engines with full vacuum advance at idle decrease in speed when the vacuum is cut off. When the idle speed is increased, the mixture normally leans out. Since the vehicles were already leaned to a lower limit, further leaning caused rough idling and lean misfiring. In a few cases, the mixture was changed on "B" vehicles and returned to the original settings upon removal of the kit.

The installation instructions in Table C-10 refer to the installation instructions supplied in the GM VSAD kit. The GM kit instructions are given in Figures D-4 and D-5 in Appendix D.

VSAD kit removals were performed in accordance with the instructions in Table C-11 in Appendix C. The vacuum lines were reconnected to the normal positions and the idle speeds adjusted to manufacturer's specifications for "C" and "D" vehicles and to MPC tune-up specifications for "B" vehicles.

The average labor cost for installing the GM VSAD kit was $7.30.

4. <u>Program Results</u>

a. Owner Acceptance

Owner Acceptance was primarily judged by three owner questionnaires and a one month interview. In the one month interview, the owner was specifically asked if he noticed a change in the performance of his vehicle. If he did, he was asked if this change was acceptable. If it was not acceptable, he was then asked if it would be acceptable if it were a part of a mandatory State program for air pollution control. The results from the questionnaires and interviews are summarized in Table 32. The owner's comments on performance after kit installation can be compared with his comments after kit removal to determine if he noticed the reverse effect of any items previously noted. The judgement of whether the vehicle performed "better" or "worse" or showed "no change" was made

TABLE 32

OWNER ACCEPTANCE OF VSAD KITS

DRIVEABILITY EVALUATIONS	% OF VEHICLES IN EACH GROUP*								
	BETTER			WORSE			NO CHANGE		
	B	C	D	B	C	D	B	C	D
Owner: After Kit Installation	22	35	32	41	35	48	37	30	20
Owner: After Kit Removal	33	32	26	45	35	30	22	33	44
CARCO Technician: After Kit Installation	32	40	34	29	26	18	39	34	48

OWNER ACCEPTANCE OF VSAD	% OF VEHICLES**		
	B	C	D
Not Acceptable	21	7	8
Acceptable	77	84	88
Acceptable if Mandatory	8	9	4

OWNER COMMENTS	% OF VEHICLES**		
	B	C	D
Overheating	11	4	6
Uses More Gasoline	28	18	16
Poorer Performance	23	6	6
Better Performance	11	11	14

* B = 100 Vehicles with MPC Tune-Ups + VSAD
C = 100 Vehicles with VSAD
D = 50 Vehicles with Dummy Kits

** In each group

by comparing the answers to each item on the questionnaires and by considering the comments solicited at the end of the questionnaires.

The numbers given in Table 32 are in percent of the vehicles in each group rather than the number of vehicles. This allows a comparison between the groups containing a different number of vehicles. The table also contains the results of the driveability tests conducted by CARCO technicians. Driveability ratings were established for these tests by assigning demerits for each driving mode found to be substandard. The ratings for tests run before kit installation were compared with those run after kit installation.

The driveability evaluations by the vehicle owners in Table 32 show that the driveability of the C vehicles with VSAD (but no other work done on the engines) was as good as that for the D vehicles with the dummy kits. The driveability evaluations by the CARCO technicians showed that more C vehicles performed "worse" and fewer of them performed "better" than the D vehicles. These differences were not significant because the average demerits detected by the CARCO technicians were 2.5 for the C vehicles compared to 1.6 for the D vehicles.

The data in Table 32 shows that 6% more owners of B vehicles with VSAD kits installed after the MPC tune-ups judged the change to be in the "worst" direction compared to owners of C vehicles with VSAD kits installed with no other work done on the engines. This does not mean that the B vehicles with VSAD performed poorer than C vehicles with VSAD. It does mean that the change in driveability was in the direction of being worse. In fact, the driveability demerits for the B vehicles with VSAD averaged 1.75 compared to 2.5 for the C vehicles with VSAD. The driveability evaluations by the CARCO technicians confirmed that VSAD on lean tuned vehicles in good repair results in a less acceptable change in driveability than VSAD on vehicles on which no other work was performed.

The owner acceptance information obtained during the one month interviews substantiates the results discussed above. As shown in Table 32, the owner answers on acceptance were very similar for the C and D groups of vehicles. Three times more owners of B vehicles stated that the change in performance was not acceptable. Part of this difference could be from the fact that seven more B vehicles overheated during a severe heat wave than C vehicles. This heat wave occurred during a period when most of the B vehicles with VSAD were in service and about half of the C vehicles with VSAD were in service. However, these overheating complaints cannot account for the fact that seventeen (17) more B vehicle owners reported poorer performance.

One reason for the change in driveability in the poorer direction with the B vehicles was caused by the leaning of the idle mixture during the kit installations. This problem was previously discussed in the preceding section. Another reason for the poorer acceptance of VSAD on the vehicles with MPC tune-ups is that VSAD and lean tuning both cause a slight loss in performance. A combination of both of these on vehicles where one of them could make the driveability marginal is likely to result in making the performance on a few vehicles unacceptable.

In general, the owners of "dummy" VSAD vehicles responded the same as the owners of C vehicles with VSAD, except that there were more changes reported in the worst direction in the initial questionnaires of the dummy vehicles than the C vehicles. It appears that the initial reactions of vehicle owners to control devices installed on their engines are likely to be exaggerated. Comments and opinions at the one month interview appear more realistic. Observations after one month--which are greater than reaction variations and bias shown by the owners of dummy vehicles--are probably real. Examples are:

(1) VSAD on engines with no other work done was acceptable to vehicle owners.

(2) VSAD on engines tuned for low emissions resulted in:

(a) Non-acceptance of about 10% of the owners.

(b) Comments from about 10% of the owners that their vehicle uses more gasoline.

(c) Comments from about 15% of the owners that their vehicle has poorer performance.

b. Side Effects of VSAD

One of the objectives of this portion of the program was to determine if there were any side effects from VSAD that would be noticed by vehicle owners during the first month of service. The scope of this study of side effects was limited to those items that would arise almost immediately in the "real-world" situation. The possible side effects of exhaust valve deterioration were not evaluated because such an evaluation would require a long range and closely controlled experiment.

When the vacuum spark advance is disconnected on an engine, the temperature of the exhaust gases increase. This increase in exhaust gas temperatures elevates the temperatures of the exhaust valves, the exhaust manifold, and exhaust systems. A study by Northrop (4) showed that VSAD does not significantly affect the coolant temperatures of most vehicles. On some vehicles, the coolant temperatures increased and on others, they decreased.

During the month of service with VSAD, there were no side effects noted (other than those previously discussed) except engine overheating. Fortunately, a week-long heat wave was encountered in Los Angeles during the time when VSAD kits were being evaluated. A total of 13 vehicle owners complained of engine overheating during this period of hot weather. Many vehicles with marginal cooling systems customarily overheat during the first siege of hot summer weather. In order to determine if these complaints of overheating were due to VSAD or other factors, seven of the vehicles were recalled to determine the cause of overheating.

These seven vehicles were tested at Olson Laboratories, Inc. Each vehicle (equipped with a GM VSAD overheat device) was instrumented to measure coolant, exhaust, and oil temperatures. Then they were dynamometer tested in a temperature controlled room at 50 miles per hour (MPH) and at idle. The load at 50 MPH was selected to provide a one degree retard of the vacuum spark advance. In general, this produces a load on the engine which is two times higher than the road load. The vehicles were tested at progressively higher temperatures of 80°F, 90°F, and 100°F under normal, VSAD and VSAD by GM kits until the coolant system boiled over. Boiling usually occurs when the engine is reduced to an idle following the 50 MPH speed. At this time, the heat stored in the engine at the higher 50 MPH temperatures soaks back into the coolant system at a time when the cooling capacity is small.

The results of the dynamometer tests are as follows:

(1) One vehicle boiled at both idle and 50 MPH with and without VSAD. This vehicle had a crack in the radiator.

(2) Three vehicles did not boil over with or without VSAD. Two of these vehicles ran cooler at idle with the GM-VSAD kit. These post-1965 vehicles supply vacuum to the distributor from a ported carburetor opening which is closed at idle. The GM-VSAD kit provided full manifold vacuum at this condition because the coolant temperature was over 205°F. The full advance increased idle speed, lowered exhaust gas temperatures and, therefore, decreased the engine coolant temperatures.

(3) Two vehicles boiled over with and without VSAD at idle. These vehicles had leaking radiator caps.

(4) One vehicle boiled over at 100°F without VSAD, at 80°F with VSAD, and at 100°F with the GM-VSAD. This vehicle had a marginal cooling system because it boiled at 100°F without VSAD. The VSAD added enough heat load to the cooling system to lower the boiling temperature to 80°F. This was the only clear case where the boil-over complaint could be directly attributed to VSAD.

The remaining six (6) vehicles of the 13 with reported overheating problems were investigated by visual inspections and interviews with the owners. The results of this investigation and the dynamometer tests above are summarized as follows:

(1) VSAD could not have been involved in the overheating of five vehicles because:

(a) Three of the five were tested at Olson Laboratories under severe conditions and they did not boil over with or without VSAD.

(b) One of the five had a dummy kit installed.

(c) One of the five was a false alarm. The red light went on once and not after that.

(2) Seven of the remaining eight vehicles had cooling systems which would not hold the proper pressure.

(a) Three had radiator leaks

(b) Three had defective radiator caps

(c) One had a rusted out freeze plug

(3) The last vehicle was tested at Olson Laboratories under severe conditions and found to boil at 80°F with VSAD and not until 100°F without VSAD.

It is concluded that cooling system defects are the major cause of engine overheating. VSAD has a small effect which would be probably only noticed on a small percentage of the vehicles with marginal cooling systems.

c. Other Problems

Other problems encountered in the installation and use of the GM-VSAD kits are as follows:

(1) The brass sleeve is constructed with a soft brass material. When tightening the hose clamps, the sleeves on some vehicles have collapsed, causing leakage of the coolant.

(2) Some vehicles have insufficient mechanical advance to allow disconnecting vacuum advance. This occurs most often with the foregin vehicles and some of the earlier domestic vehicles. VSAD on these vehicles gives extremely poor driveability and is likely to cause exhaust valve damage and cracked exhaust manifolds.

(3) The kit is difficult to install on some of the foreign vehicles. It is nearly impossible to install on Toyota and Datsun vehicles because the hoses between the engine and radiator are not long enough.

(4) A VSAD kit was installed on a Ford Falcon 6 cylinder engine by mistake. This engine has only vacuum spark advance. As a result, the exhaust manifold cracked due to excessive heat after four days of freeway driving to and from work--20 miles each way.

(5) The installation of the GM-VSAD kit on some post-1965 vehicles which normally run hot can result in an idle speed that is too fast. When the coolant temperature reaches 205°F, full vacuum spark advance is supplied to the distributor causing the engine to speed up. The idle speeds on many of these vehicles with "engine modification type" exhaust controls are already high. This additional increase in idle speed was unacceptable to two of the vehicle owners.

5. Conclusions

(a) Vehicle owners could not distinguish between VSAD kits and dummy kits when the VSAD kits were installed with no other work on the engine.

(b) The installation of VSAD kits on vehicles with MPC tune-ups produced driveability changes that were unacceptable to many owners. This problem could probably be alleviated by a carburetor adjustment at the time of VSAD kit installation.

(c) The effect of VSAD on cooling system temperatures is small. VSAD causes overheating in a small percentage of vehicles with marginal cooling systems. The major cause of overheating in hot weather is defective cooling systems. If VSAD is used to control NO_X in used vehicles, the kit installation instructions should include the inspection and repair of radiator defects.

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